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NOISE CHARACTERISTICS OF THE O-1 AIRPLANE AND SOME APPROACHES TO NOISE REDUCTION

By Andrew B. Connor, David A. Hilton, W. Latham Copeland, and Lorenzo R. Clark

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16. Abstract

NASA, at the request of the DOD, has undertaken a brief study of the O-1A airplane to determine possible means for reducing the aircraft aural detection distance. This effort involved measuring the noise signature of the basic airplane, devising methods to attenuate the noise, and then estimating the effect of several selected modifications on the aural detection distance of the aircraft.

A relatively simple modification utilizing a 6.5 ft diameter, six-blade propeller and including a muffler having a volume of 0.725 cu ft is indicated to reduce the aural detection distance of the O-1 aircraft from about 6 miles at an altitude of 1,000 ft and 2 to 3 miles at an altitude of 300 ft to approximately half these values.

The flyover noise data suggest that routing the exhaust stacks up and over the wing would provide immediate noise reduction of about 5 dB with an attendant reduction in detection distance. Furthermore, all these studies confirm the work of other investigators that the 1/3 octave band (center frequency=125 cps) is the most critical in reducing aural detection distance.

A further result of these studies is that the aural detection distance of the unmodified aircraft might be reduced significantly by artifically raising the low frequency ambient noise levels by some means such as the operation of an additional and diversionary airplane.

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SUMMARY

NASA, at the request of the Department of Defense, has undertaken a brief study of the O-1A airplane to determine possible means for reducing the aircraft aural detection distance. This effort involved measuring the noise signature of the basic airplane, devising methods to attenuate the noise, and then estimating the effect of several selected modifications on the aural detection distance of the aircraft.

A relatively simple modification utilizing a 6.5 ft diameter, six-blade propeller and including a muffler having a volume of 0.725 cu ft is indicated to reduce the aural detection distance of the O-1 aircraft from about six miles at an altitude of 1,000 ft and 2 to 3 miles at an altitude of 300 ft to approximately half these values.

The flyover noise data suggest that routing the exhaust stacks up and over the wing would provide an immediate noise reduction of about 5 dB with an attendant reduction in detection distance. Furthermore, all these studies confirm the work of other investigators that the third octave band (center frequency = 125 cps) is the most critical in reducing aural detection distance.

A further result of these studies is that the aural detection distance of the unmodified aircraft might be reduced significantly by artificially raising the low frequency ambient noise levels by some means such as the operation of an additional and diversionary airplane.

INTRODUCTION

At the request of the Department of Defense a study has been made of potential noise reduction for the O-1A aircraft, expressed in terms of the noise detection distance. This effort specifically involves: (1) documenting the airplane's noise characteristics, (2) performing a quick evaluation of fixes and their potential noise reduction, (3) estimating the effects of the noise reduction modifications on the airplane's performance and stability, and (4) estimating the effect of several selected modifications on the aural detection distance of the aircraft. This paper documents the NASA effort to accomplish the above objectives.

APPARATUS AND METHODS

Test Airplane

The O-1A airplane is a two-place high-wing monoplane of approximately 2100 pounds gross weight. It has a horizontally opposed six-cylinder reciprocating engine rated for take-off at about 213 horsepower and with direct drive to a fixed pitch, two-bladed, 90-inch diameter propeller. Photographs of the test airplane are shown in figure 1, and a three-view drawing with a list of the principal physical dimensions is shown in figure 2. The airplane was provided by Fort Eustis, Virginia, and flown by a test pilot from the U.S. Army Aviation Materiel Laboratories.

Test Conditions

Noise measurement tests were conducted on August 27, 196[illegible], at the NASA Wallops Island flight test facility and use was made of the main paved runway surface and the associated flat terrain for locating instrumentation for performing both static and flyby tests. The terrain features can be clearly seen in figure 3(a) which is a photograph showing the microphone array looking north from the centerline, and figure 3(b) which is a view looking south. The microphone arrays for both the static and flyover measurements are illustrated by the diagrams of figure 4.

Noise Measuring Equipment

The noise measuring instrumentation for these tests is illustrated by the block diagram of figure 5. The microphones were of a conventional condenser type having a frequency response flat to within ± 3 dB over the frequency range of 20 to 12,000 cps. The outputs of all the microphones at each station were recorded on multi-channel tape recorders. The entire sound measurement system was calibrated in the field by means of conventional discrete frequency calibrators, supplied by the microphone manufacturers, before and after the flight measurements. The data records were played back from the tape (using the playback system shown in figure 5) to obtain the sound pressure level time histories and both broad-band and narrow-band spectra.

Aircraft Operation

Static noise surveys.- The aircraft was operated at two engine speeds, 1,700 and 2,200 rpm for static noise measurements. These data were taken with the microphone static array as shown in figure 4 where microphones were positioned at 30 degree intervals on a 50-foot radius from the propeller hub.

Flyover noise surveys.- In the flyover noise tests the aircraft was flown over a ground track as shown on figure 4. The aircraft was operated at 1,750 and 2,250 rpm, at altitudes from 50 - 690 ft. above the runway and at speeds from 60 to 105 mph (See Table I.). Precise geometric altitude and course direction were measured by the GSN-5 radar tracking unit. Position information was provided as an assist to the pilot to maintain proper course and altitude. The desired course flight path was maintained for about one mile prior to and beyond the overhead position. Some data were also obtained for the gliding condition as indicated by figure 4 (engine rpm = 800).

Atmospheric Conditions

During the times of the tests, observations of surface temperature, humidity and wind velocity, and direction were made at the control tower which is within about 1,000 ft. of the test area. The temperature varied from about 86 - 88°F, the wind velocity was 12 kts from the northwest, and the dew point varied from 58°F to 55°F.

MEASURED NOISE CHARACTERISTICS OF THE BASIC AIRCRAFT

Static ground tests.- The overall sound pressure levels which were measured in the 50-foot radius static array are presented in figure 6. This figure shows a comparison of the overall noise radiation patterns for both maximum rpm and flight idle rpm conditions. The radiation patterns are nearly circular in shape although somewhat distorted by the wind. It can be seen that the noise levels associated with the lower power condition are from 4 to 10 dB lower than for the higher power condition.

In figure 7 are presented octave band analyses of data obtained at the 90° microphone position of figure 6. These data illustrate the general nature of the octave band spectra obtained for this aircraft and thus are plotted for only one azimuth angle. Data for other azimuth angles and for both power conditions are listed in Table II. For the lower rpm condition the highest noise levels occur in the second octave band and the levels are generally lower for the higher octave bands. Likewise for the higher power condition the highest levels are noted to occur in the third and fourth octave bands.

In figure 8 is presented a narrow-band analysis of the noise for the cruise power condition of figure 7. The nominal engine setting for cruise was 2,250 rpm; however, analysis resolved the static engine setting to be 2,200 rpm as shown on figure 8. The 50 rpm difference is not expected to show any major effects on the subsequent analyses. These data were obtained with the aid of a three cps band width filter for the range of frequencies up to about 500 cycles. Shown in the figure are the individual noise components corresponding to the significant engine firing frequencies and the propeller noise frequencies. The engine firing frequencies are indicated as some integral multiple times f which for a four-cycle engine such as this is equal to the revolutions per second divided by two. The propeller noise components are identified by the given mB values where m is the order of the harmonic and B is the number of blades which for this airplane is equal to two. The data of figure 8 illustrate the type of information obtained from the narrow band analyses and Table III contains a listing of similar data for several other azimuth positions. Data such as those of figure 9 and Table III make possible the identification of the various sources of noise on the aircraft. It can be seen that some of the engine firing frequencies and the propeller noise frequencies are coincident and thus cannot be separated experimentally for analysis. In cases where they were coincident, the propeller noise amplitudes were estimated from theoretical considerations (See Appendix A.). The data of the figure, however, show that some of the highest noise level components are associated with the engine exhaust for this operating condition.

Flyby tests.- Figure 9 contains flyover noise data for both the cruise and flight idle power conditions and for the altitude range 550 to 590 ft. The data were obtained from one microphone in the ground array of figure 4(b) located near the centerline of the runway. In this figure, overall sound pressure levels are plotted as a function of time measured from an arbitrary reference time. The flight direction of the aircraft is from left to right in the figure. For both power conditions the noise builds up to a peak value when the aircraft is nearly overhead. This peak value is sustained for a short period of time and then the noise levels generally decrease as the aircraft continues on its flight path. The greatest differences in the noise levels for the two power conditions occur when the aircraft is nearly overhead. As a matter of interest the curve at the bottom has been included to represent the measured noise from this airplane in a glide condition for which the engine was not cut-off but was operating at a very low rpm. For this latter glide condition the estimated altitude overhead the measuring station was about 300 ft. The noise generated by the aircraft in the glide condition was generally submerged in the background noise; however, the approach of the aircraft was detectable to human observers even though the instruments indicated no distinct noise peak as it passed overhead.

During the measurements of the flyover noise data of figure 9, the opportunity was also taken to make time history measurements of the noise at several distances to each side of the airplane ground track. These data are presented in figure 10. Measurements were made at distances up to about 1,000 ft. on each side of the ground track. The noise levels decreased as a function of lateral distance on both sides of the track. Based on the inverse distance law, taking account of the slant ranges to each of the measuring stations, and assuming the noise source to be nondirectional, measured values about 6 dB less than those on the ground track would be expected at the 1,000 ft. measuring stations. The measured levels are of the order of 12 dB less at the remote stations thus indicating a dropping off of noise level substantially faster than the inverse distance law. It is believed that the above result is due to the fact that the in-flight noise radiation pattern is not symmetrical. The fact that the exhaust stacks are underneath the fuselage, as shown in figure 1(a), would tend to support this conclusion. It follows then that if the exhaust stacks were redirected upward, a noise reduction of approximately 5 dB might be obtained with a consequent reduction in the maximum aural detection distance. It should also be noted here that although ground measurements are necessary for identifying the noise sources, flight data are necessary to accurately assess detection distance.

Octave band spectra have been measured underneath the aircraft for the flight conditions of figure 10 and these data are presented in figure 11. The data represent the maximum values in each octave band as the aircraft flies overhead regardless of when that maximum value occurred. Data are presented for two power conditions. Ambient noise level data are also included. It can be seen that these spectra for the aircraft in flight have a somewhat different shape than for comparable operating conditions of rpm for the static case. Part of the difference in the shapes particularly at the high frequencies is, of course, due to the increased atmospheric absorption for the greater distances of the flyby tests. These data will be used in the ensuing sections which deal with detection distance.

AIRCRAFT MODIFICATIONS ANALYZED FOR THIS STUDY

Several modifications were evaluated in this analysis in a parametric study of propellers and mufflers. Three combinations were finally selected as having the best potential for reducing the aural detection distance of the O-1 airplane. Details of this estimating process are presented in Appendixes A through D which treat of propeller analysis, muffler analysis, weight estimates, and the effects of all these on the airplane. The pertinent parameters describing the three modifications are listed in Table IV.

The table indicates that greater weight penalties accrue to the constant speed propeller compared to fixed pitch; but, the performance analysis in Appendix D shows that the constant speed propeller compensates for the additional weight such that the airplane performance is as good or better than the basic airplane. The fixed pitch propellers on the other hand, even though of lesser weight, generally result in performance losses.

ESTIMATED NOISE CHARACTERISTICS OF THE MODIFIED AIRCRAFT

One of the main objectives of the modifications was to substantially reduce the noise in the lower octave bands since the previous experience of references 1 and 3 indicates these were most critical from the standpoint of detection. It can be seen that substantial reductions in noise level in the lower octave bands are estimated for each of the modifications.

A summary of the noise reduction estimates for the three modifications compared to the basic airplane is shown in figure 12. This figure is a plot of octave band spectra for a distance of 570 ft for each of the four cases, i.e. the basic aircraft and the three modifications. A distance of 570 ft was chosen as a reference because that was the actual measured distance from the test airplane. The overall sound pressure levels for each of the four cases are shown to the left of the figure adjacent to the ordinate scale. The estimated spectra for the modified aircraft of figure 12 were based on the measurements of references 1 and 2 and the calculations of Appendixes A and B.

DETERMINATION OF AURAL DETECTION DISTANCES

Basic Assumptions Relating to Detection

In addition to the noise source characteristics (See refs. 1 and 2.) it is well-known that the aural detection of a noise involves such factors as the transmission characteristics of the path over which the noise travels (See refs. 3, 4, 5, 6, and 7.) and the acoustic conditions at the observer location (See refs. 4 and 8.) as well as the hearing ability of the observer (See ref. 9). Attempts have been made to account for all of the pertinent factors in the above categories for the calculations of detection distance which follow.

Attenuation factors.- The attenuation factors associated with the transmission of noise from the source to the observer are assumed to involve the well-known inverse distance law, atmospheric absorption due to viscosity and heat conduction, small-scale turbulence, and terrain absorption which is weighted to account for the elevation angle between the source and the observer. For the purposes of this paper these factors are taken into account as determined by the following equation:

$$\text{P.L.}\ (f,x) = 20 \log_{10} \frac{x}{A} + \left[K_1 + K_2 + (K_3 - K_1)\ K_4\right] \frac{x}{1000}$$

where propagation loss (P.L.) is computed for each frequency and distance combination and where the first term on the righthand side of the equation accounts for the spherical spreading of the waves. In this connection x is the distance for which the calculation is being made and A is the reference distance for which measured data are available. The remaining terms which represent propagation losses and which are given in coefficient form are defined as follows:

K_1 represents the atmospheric absorption due to viscosity and heat conduction and is expressed in dB per 1,000 ft. The values of K_1 vary as a function of frequency and for the purposes of this paper are those of the following table. For frequencies up to 500 cps data are taken from reference 3 and for the higher frequencies from reference 6.

Octave Band No.	Center Freq.	dB Loss Per 1000 Ft.
1	31.5	
2	63	.1
3	125	.2
4	250	.4
5	500	.7
6	1000	1.4
7	2000	3.5
8	4000	7
9	8000	14.5

K_2 is the attenuation in the atmosphere due to small-scale turbulence. A value of 1.3 dB per 1,000 ft. is assumed independent of frequency for the frequency range above 250 cycles (See ref. 7.).

K_3 also is expressed in dB per 1,000 ft. and includes both atmospheric absorption and terrain absorption. The values used are those of reference 4 which are listed for widely varying conditions of vegetation and ground cover. The data of reference 4 have been reproduced in a more convenient form in reference 5. Calculations included herein make use of the data of reference 5 particularly curve (b) of figure 1 which represents the condition of thick grass cover (18 in. high) and the upperbound of curve 3 of figure 2 which represents conditions of leafy jungle with approximately 100 ft. "see through" visibility. K_4 is a weighting factor to account for the angle, measured from the ground plane, between the noise source and the observer. The values of K_4 assumed for the present calculations were taken from figure 3 of reference 5 and are seen to vary from zero for angles greater than 7^o to 1.0 for an angle of 0^o.

Ambient noise level conditions and human hearing.- The detectability of a noise is also a function of the ambient masking noise conditions at the listening station and the hearing abilities of the listener. Since they are somewhat related, they will be discussed together.

The ambient noise level conditions assumed for these studies were based on data from references 4 and 8 which were obtained in jungle environments. It was indicated in reference 3 that a noise made up of discrete tone components is detectable if it is within 9 dB of the background noise (random in nature) in any particular octave band. Thus, the corresponding measured spectra of references 4 and 8 have been reduced by 9 dB to account for the above difference in the masked and the masking spectra.

The resulting octave band spectra have been further adjusted to account for critical band width of the human ear, according to the following equation, to give masking level values for each band.

$$\text{Masking Level, dB} = \text{octave band level, dB} - 10 \, \text{Log}_{10} \left[\frac{\Delta f_{octave}}{\Delta f_{critical}} \right]$$

where the Δf_{octave} and $\Delta f_{critical}$ values corresponding to standard octave band center frequencies are given in the following table:

Octave Band Center Freq., cps	31.5	63	125	250	500	1000	2000	4000	8000
Δf_{octave}, cps	22	44	88	177	354	707	1414	2828	5656
$\Delta f_{critical}$, cps	--	--	50	50	50	66	100	220	500
$10 \, \text{Log}_{10} \frac{\Delta f_{octave}}{\Delta f_{critical}}$	--	--	2.5	5.5	8.5	10.7	11.5	11.1	10.5

The values of the last column in the above table have been subtracted from the octave band values to adjust them to the masking level spectra which define the boundaries of the jungle noise criteria detection region of figures 13 through 16.

Likewise a threshold of hearing curve (taken from ref. 3) is made use of since it represents the levels of pure tone noise that are just detectable on the average by healthy young adults. The implication here is that noises having levels lower than those of the threshold of hearing curve at corresponding frequencies will not be detectable. Thus the threshold of hearing curve is the determining factor of detection at the lower frequencies.

No attempt is made to account for possible binaural effects in the studies of the present paper.

Determination of Aural Detection Distances for

Basic and Modified Aircraft

Reference detection distances for each aircraft configuration, for flight altitudes of 300 and 1000 ft. and for ground cover conditions representative of both 18-in. grass and 100 ft. "see-through" leafy jungle have been determined with the aid of the data of figures 13 through 16. In these latter figures the octave band noise levels at various distances have been estimated by taking into account the appropriate atmospheric and terrain losses. Also shown on each of the above figures is a threshold of hearing curve from reference 5 and a band labeled "Jungle Noise Detection Criteria." The lower boundary of this area represents masking levels in a relatively quiet jungle location in the Canal Zone (See ref. 4.). The upper boundary on the other hand represents a relatively more noisy masking level condition in Thailand (See ref. 8.). In the determination of the maximum distances at which the aircraft could be detected aurally, it was assumed that such detection was possible at distances at which the level of aircraft noise in any octave band equalled or exceeded either the masking level curve or the threshold of hearing curve whichever was more appropriate. The results of such estimates are included in Table V for each configuration and the two altitude and ground cover conditions. The top row of values for each altitude condition is associated with the upper boundary of the jungle noise detection criteria region whereas the lower row of values is associated with the lower boundary. The data of the table illustrate the effects of each of the variables that are significant in aural detection, that is: aircraft altitude, ground cover, noise source characteristics, and masking noise characteristics at the observer station.

Aircraft altitude.- In general, detection distances are shorter for lower aircraft altitudes for both ground cover conditions. This is due to the fact that at the lower propagation angles (from aircraft to observer), associated with the lower altitudes, terrain absorption effects are more important.

Ground cover.- For all configurations and operating conditions the leafy ground cover (100 foot "see-through" distance) results in detection distances which are equal to or smaller than those for the 18-inch high grass condition. This result is due to the fact that the terrain loss coefficients are larger for the more dense vegetation.

Aircraft configuration.- Reading from left to right, the aircraft configurations of Table V have progressively decreasing values of overall noise level. The associated detection distances decrease accordingly except for some operating conditions of modification No. 1. It can be seen from the data of figure 12 that some of the acoustic power is shifted to the fourth octave (250 cps center frequency) with the result that the third octave band level is lower than that for modification 2. This points up the particular importance of reducing the lower octave band levels.

A relatively simple modification utilizing a 6.5 ft diameter, six-blade propeller and including a muffler having a volume of 0.725 cu ft is indicated to reduce the aural detection distance of the O-1 aircraft from about 6 miles at an altitude of 1,000 ft and 2 to 3 miles at an altitude of 300 ft to approximately half these values. Corresponding weight increases of 3.5 and 25 pounds are forecast using a fixed-pitch and a controllable-pitch propeller, respectively.

A more ambitious modification requiring 1.5:1 engine gearing and a larger muffler is indicated to reduce the aural detection distance based on the criteria chosen for this paper to approximately 1-1/5 mile at an altitude of 300 feet. Data are also presented for a third modification which provides an even greater reduction in detection distance. In this case the weight analysis showed that the cg was shifted forward beyond the aircraft design structural limits.

The flyover noise data suggest that routing the exhaust stacks up and over the wing would provide an immediate noise reduction of about 5 dB with an attendant reduction in detection distance. However, the effects of this possible modification on the airplane weight and performance have not been treated in this paper.

A re-examination of the modified airplane analyses indicated that a better result might be obtained by matching the modification No. 1 propeller to the modification No. 2 muffler. This approach would shift the noise levels of the third octave band downward to the same level as modification No. 1, as shown on figure 12, would maintain the reduced noise levels in the fourth octave band (modification No. 2), and the net result would be a reduction in detection distance compared to those of modifications No. 1 or 2.

Ambient masking levels.- The upper and lower values of Table V represent the differences between the use of the upper and lower boundaries of the jungle noise detection criteria region of the figures as the basis for detection. It is obvious that higher masking level values always result in smaller detection distances. This suggests that an alternative procedure of artifically raising the masking noise level in a particular area to decrease the detection distance may be useful in some special situations.

CONCLUDING REMARKS

A study was conducted to reduce the aural detection distance of the O-1A aircraft. This effort involved documenting noise characteristics of the airplane, devising modifications to reduce the noise, and estimating the reduction in detection distance as a result of the modifications.

A relatively simple modification utilizing a 6.5 ft diameter, six-blade propeller and including a muffler having a volume of 0.725 cu ft is indicated to reduce the aural detection distance of the O-1 aircraft from about 6 miles at an altitude of 1,000 ft and 2 to 3 miles at an altitude of 300 ft to approximately half these values. Corresponding weight increases of 3.5 and 25 pounds are forecast using a fixed-pitch and a controllable-pitch propeller, respectively. Use of the latter is indicated to provide essentially the same performance envelope of which the unmodified O-1A aircraft is capable.

A more ambitious modification requiring 1.5:1 engine gearing and a larger muffler is indicated to reduce the aural detection distance based on the criteria chosen for this paper to approximately 1-1/5 mile at an altitude of 300 feet. Again, use of a controllable-pitch propeller will cause no degradation in performance compared to the unmodified O-1A aircraft despite a weight increase of 115 pounds.

Results of this study indicate that a relatively simple modification of redirecting the exhaust stacks upward and above the wing may provide a modest noise reduction with an associated modest reduction in aural detection distance. More extensive modifications to the exhaust system and modifications to the propeller and drive would result in more substantial noise reductions and further reductions in aural detection distance. Furthermore, these studies confirm the work of otherinvestigators that the third octave band (center frequency = 125 cps) is the most critical in reducing aural detection distance.

A further result of these studies is that the aural detection distance of the unmodified aircraft might be reduced significantly by artifically raising the low frequency ambient noise levels by some means such as the operation of an additional and diversionary airplane.

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Table I.- Summary of O-1A operating conditions.

flight no.	altitude above runway, ft.	lateral disp. from runway ℄, ft.	velocity MPH	engine speed, RPM
Powered Flight Conditions				
1	690	0	60	1700
2	550	30	60	1750
3	680	20	105	2250
4	590	20	105	2250
5	280	0	105	2250
6	285	0	105	2250
7	50	10	105	2250
Gliding Flight Conditions				
8	400 to 100	0	70	800
9	400 to 100	0	70	800

Table II.- Broad-band analysis of noise measured on the test airplane at a distance of 50 feet at cruise power.

Azimuth angle, ψ, deg	Noise level, dB									
	Over-all	22 to 44 cps	44 to 88 cps	88 to 177 cps	177 to 354 cps	354 to 707 cps	707 to 1414 cps	1414 to 2828 cps	2828 to 5656 cps	5656 to 11,312 cps
Cruise power (2250 RPM)										
0	105	71	91	99	98	96	95	94	93	97
330	104	71	93	100	98	95	94	91	91	93
300	104	74	94	99	99	94	92	90	84	94
270	107	76	98	102	102	97	94	97	93	94
Partial power (1750 RPM)										
0	100	76	96	93	83	83	91	87	83	82
330	100	74	96	94	95	94	93	86	85	84
300	100	73	97	95	94	93	89	80	74	78
270	101	74	98	94	87	84	84	85	83	82

Table III.- Narrow-band analysis of noise measured on the test airplane at a distance of 50 feet at cruise power.

Noise Component Freq., cps	Harmonic		Noise Level, Decibels Azimuth Angle,			
	Propeller	Engine Firing	0°	30°	60°	90°
36.5		2	65	--	--	69
55		3	68	74	84	79
73	2	4	86	92	94	97
92		5	68	75	--	76
110		6	96	99	97	99
128		7	69	70	--	70
146	4	8	90	92	96	97
165		9	74	84	91	88
183		10	77	76	76	73
202		11	--	70	--	73
220	6	12	96	97	98	99
238		13	--	72	73	76
257		14	86	87	79	81
274		15	81	79	87	89
293	8	16	97	95	91	92
312		17	74	77	78	69
330		18	87	87	89	82
348		19	--	75	75	69
367	10	20	97	90	91	92
385		21	86	71	--	79
404		22	--	75	--	70
422		23	77	76	82	81
440	12	24	93	94	89	90
458		25	--	74	--	70
476		26	--	79	--	72
513	14	28	87	91	85	90
550		30	--	80	--	74
586	16	32	88	86	77	85
660	18	36	86	86	80	84
733	20	40	84	88	77	--
806	22	44	85	83	81	--

Table IV Summary of Aircraft Modifications.

Aircraft Configuration	Propeller				Muffler		Net Aircraft Weight Increase, Lbs	Estimated Overall Noise Level (Distance = 570 [illegible])
	Engine rpm / Prop rpm	Dia., Ft	No. of Blades	Type*	Volume [illegible]	Location**		
[illegible] A	1:1	7.5	2	F.P.				[illegible]
Modification 1-A	1:1	6.5	6	F.P.	.725	Ext.	3.5	
B	1:1	6.5	6	C.P.	.725	Ext.	25	77 dB
Modification 2-A	1.5:1	7.5	5	F.P.	1.54	Ext.	75	
B	1.5:1	7.5	5	F.P.	1.54	Int.	89	70 dB
C	1.5:1	7.5	5	C.P.	1.54	Int.	115	
Modification 3-A	2:1	7.5	5	F.P.	[illegible].15	Ext.	[illegible]	
[illegible]	2:1	7.5	5	[illegible]	[illegible]	Int.	[illegible]	[illegible]
C	2:1	7.5	5	C.P.	6.15	Int.	255	

*F.P. - Fixed Pitch Propeller
C.P. - Controllable-Pitch Propeller

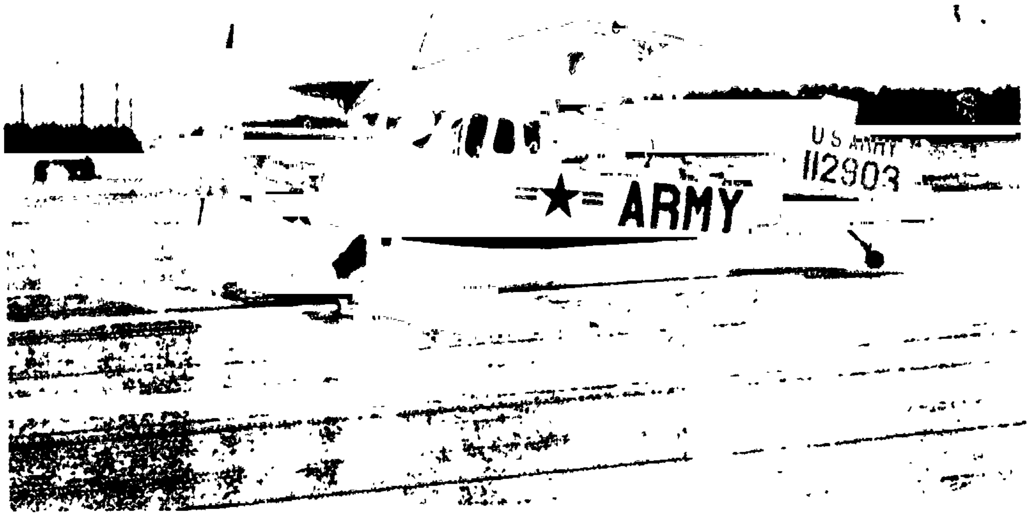
**Ext. - External (Belly Location)
Int. - Internal (Within Fuselage Aft of Cabin)

Table V.- Reference aural detection distances in feet for the basic O-1A Aircraft and for three proposed modifications. Data are for two aircraft altitudes and for two ground cover conditions. (Top row of values listed for each condition relate to the upper boundary of the jungle noise detection criteria region whereas the lower row of values relate to the lower boundary.)

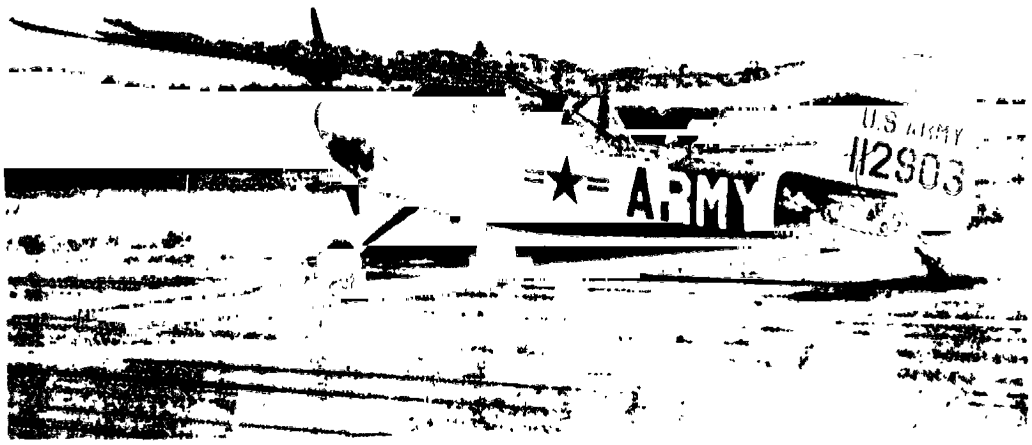
aircraft altitude, ft.	ground cover	reference detection distance, ft.				
		AIRCRAFT CONFIGURATION				
		basic	basic**	mod. 1	mod. 2	mod. 3
1000	grassy	30,000 32,000	25,000 28,000	13,500 17,000	19,500 22,500	6,600 9,200
1000	leafy	30,000 32,000	25,000 28,000	12,500 15,000	17,500 20,000	6,600 8,700
300	grassy	15,500 16,500	13,000 14,000	9,500 11,000	10,000 11,000	6,000 7,500
300	leafy	8,700 9,300	8,100 8,700	*6,100 *7,300	6,000 6,600	4,200 5,000

* data from 4th. octave band

** basic aircraft assuming over-wing exhaust

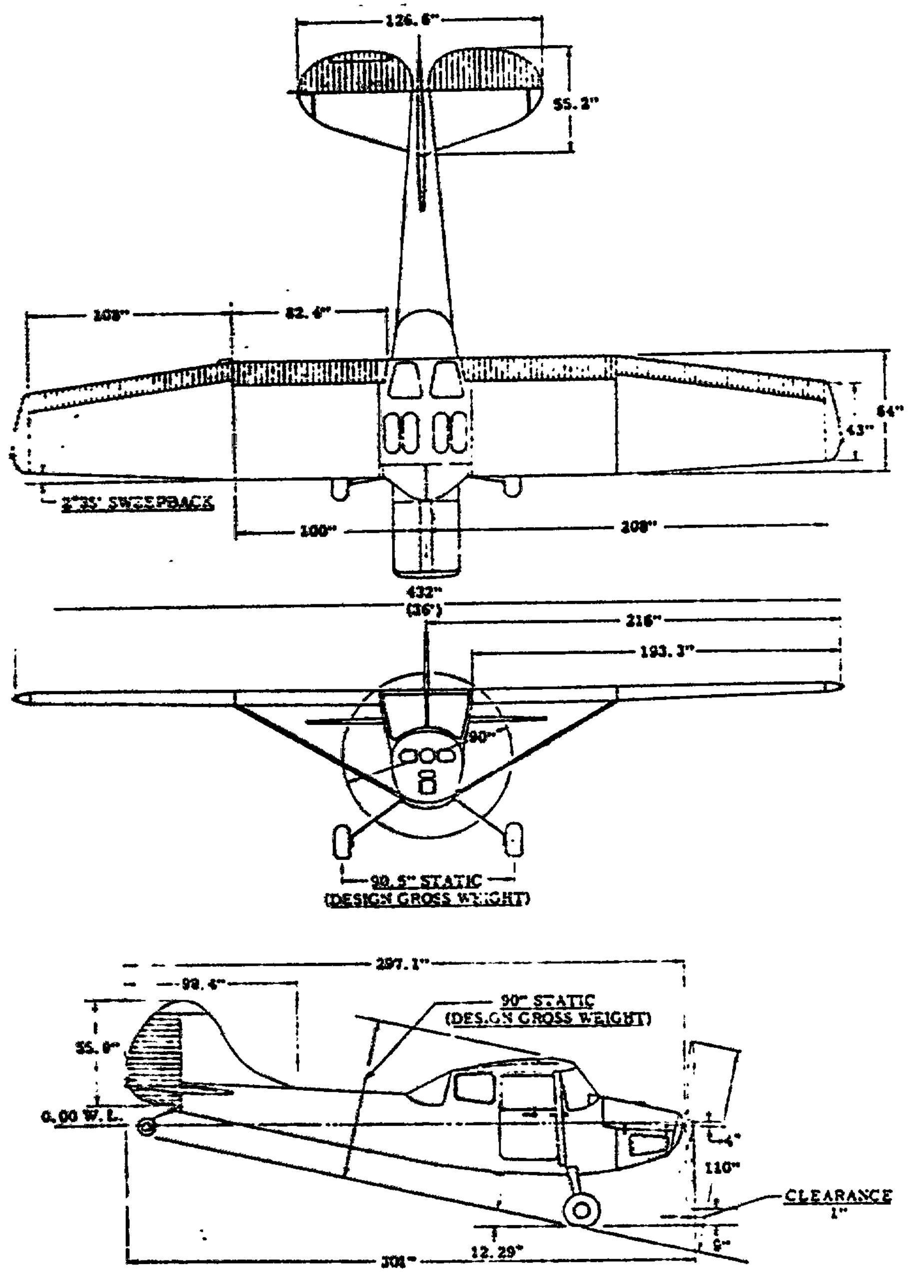


(a) Front Quartering View



(b) Rear Quartering View

Figure 1.- Photographs of the O-1A aircraft.

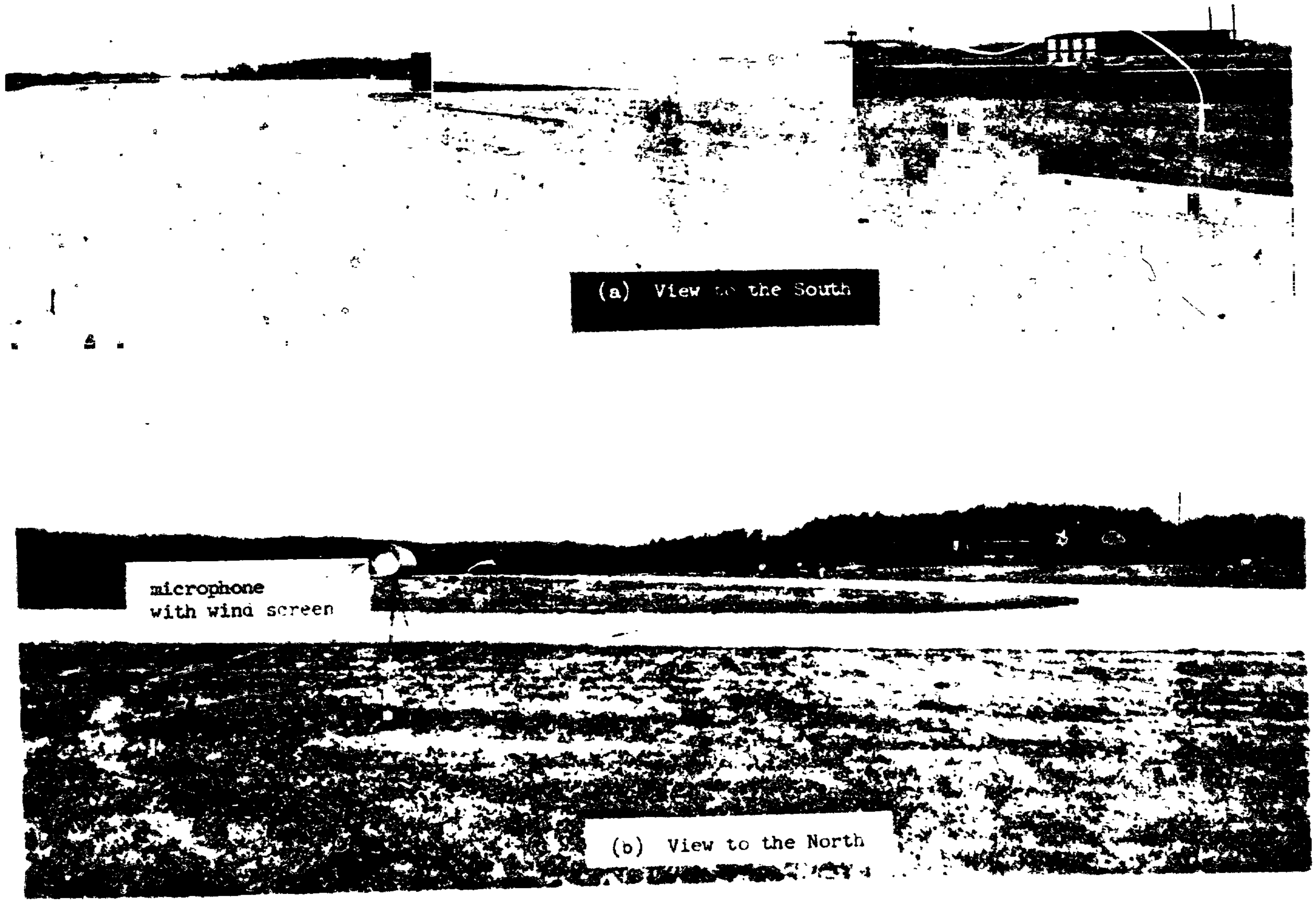


PRINCIPAL DIMENSIONS.

General (Aircraft in level flight position unless otherwise stated.)

Span	36 ft.
Length (over-all)	25 ft. 1 in.
Length over-all on the ground, propeller horizontal)	25 ft.
Height (propeller horizontal)	7 ft. 6 in.
Height (Tailwheel on ground, propeller vertical)	9 ft. 2 in.
Design Gross Wt.	2100 lb.
WINGS	
Type	High
Airfoil section (curve identification)	NACA 2412
Chord at root	5 ft. 4 in.
Chord near tip (18 ft. from fuselage centerline)	3 ft. 7 in.
Incidence -- root	+1° 30'
Incidence -- tip	-1° 30'
Dihedral (measured on top face of front spar)	2° 6'
Sweepback (outboard panel)	2° 35'
Aspect Ratio	7.35
STABILIZER	
Span	10 ft. 6.6 in.
Maximum chord (including elevator)	4 ft. 5 in.
Incidence	-4°
Dihedral	0°
FUSELAGE	
Width (maximum)	3 ft. 9 in.
Height (maximum)	5 ft. 3 in.
Length (without engine mount and tail wheel bracket)	19 ft. 8 in.
Length (with engine mount and tail wheel bracket)	22 ft.
Height of door level above ground (static)	2 ft. 8 in.
Door Dimensions	33 in. x 45 in.
Stowage space	9.27 cu. ft.
Stowage space (rear seat removed)	20.09 cu. ft.
AREAS	
Wings (less ailerons, including fuselage)	155.7 sq. ft.
Ailerons (total)	18.3 sq. ft.
Flaps (total)	21.24 sq. ft.
Stabilizers (including elevators)	35.18 sq. ft.
Elevators (two, including tab)	15.93 sq. ft.
Elevator Trim Tab (total)	0.92 sq. ft.
Fin	9.00 sq. ft.
Rudder (including tab)	9.42 sq. ft.

Figure 2.- Three-view line drawing of the O-1 aircraft including principal dimensions and physical characteristics.



(a) View to the South

(b) View to the North

Figure 3.- Photographs of the NASA Wallops Island test area showing the runway and flat terrain.

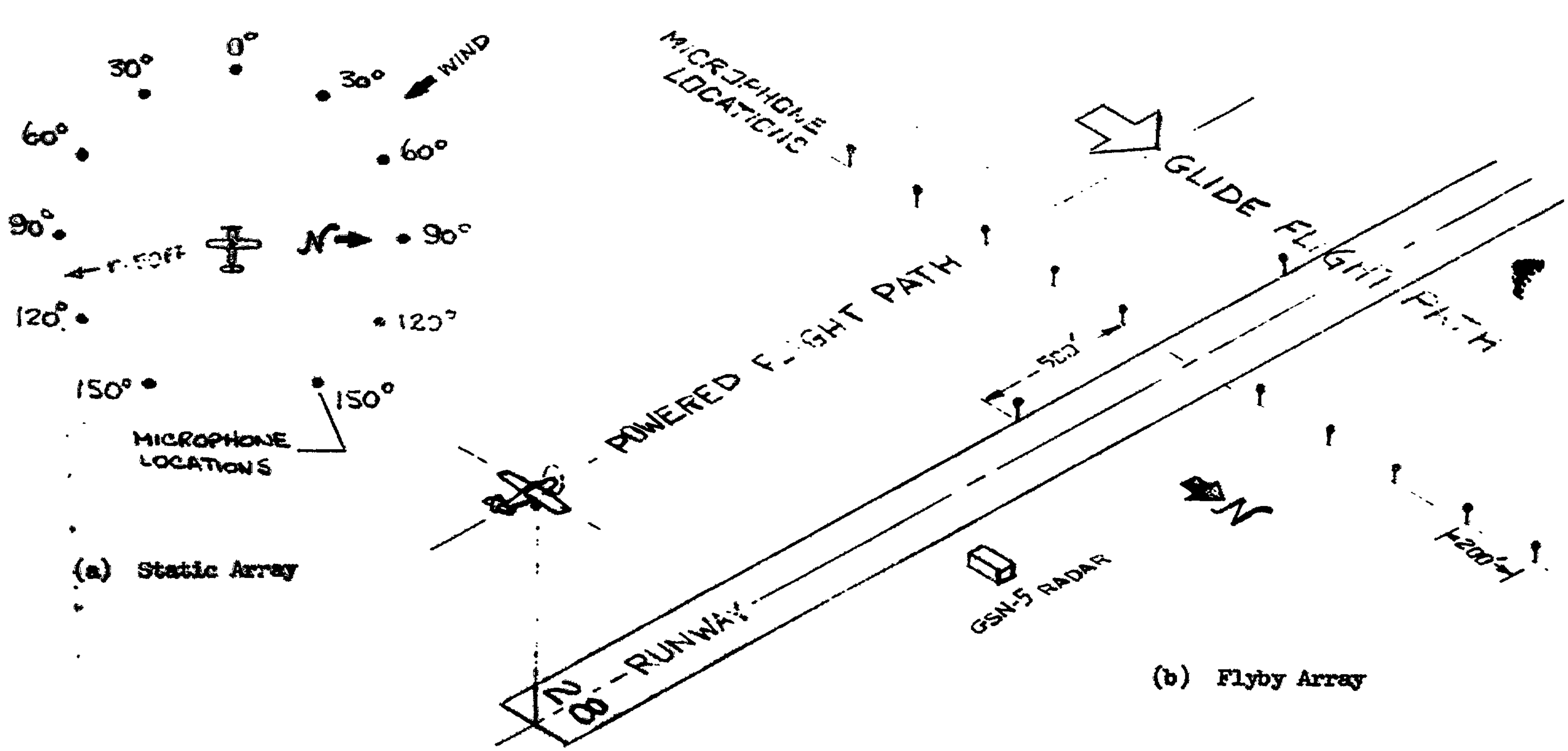
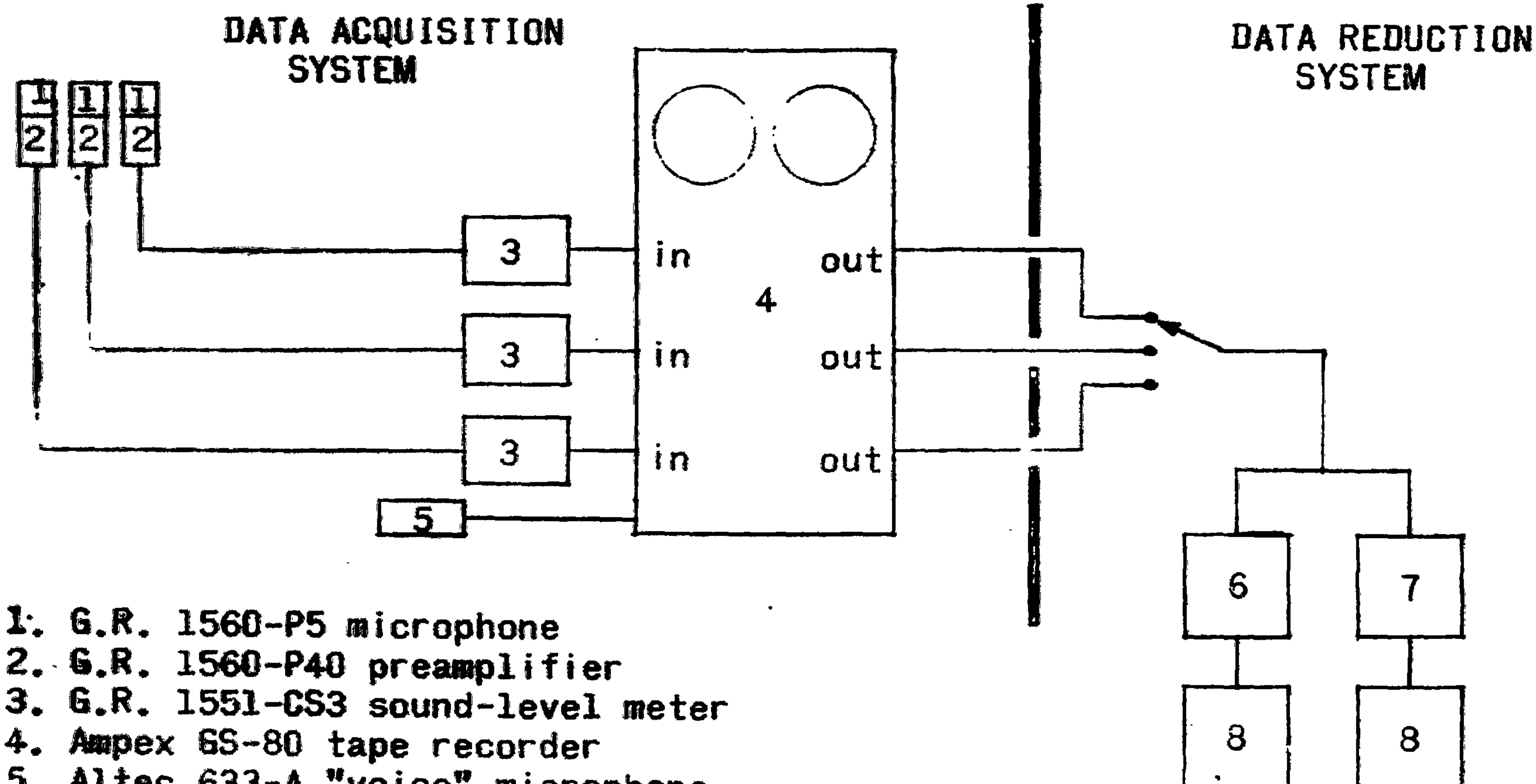


Figure 4.- Schematic diagram of the test area showing the runway, the radar, the flight paths, and the microphone arrays for both the static and flyby tests.



1. G.R. 1560-P5 microphone
2. G.R. 1560-P40 preamplifier
3. G.R. 1551-CS3 sound-level meter
4. Ampex 6S-80 tape recorder
5. Altec 633-A "voice" microphone
6. G.R. 1558-AP octave-band analyzer
7. G.R. 1900-A wave analyzer
8. G.R. 1521-B graphic level recorder

Figure 5.- Block diagram showing system layout for noise data acquisition and reduction.

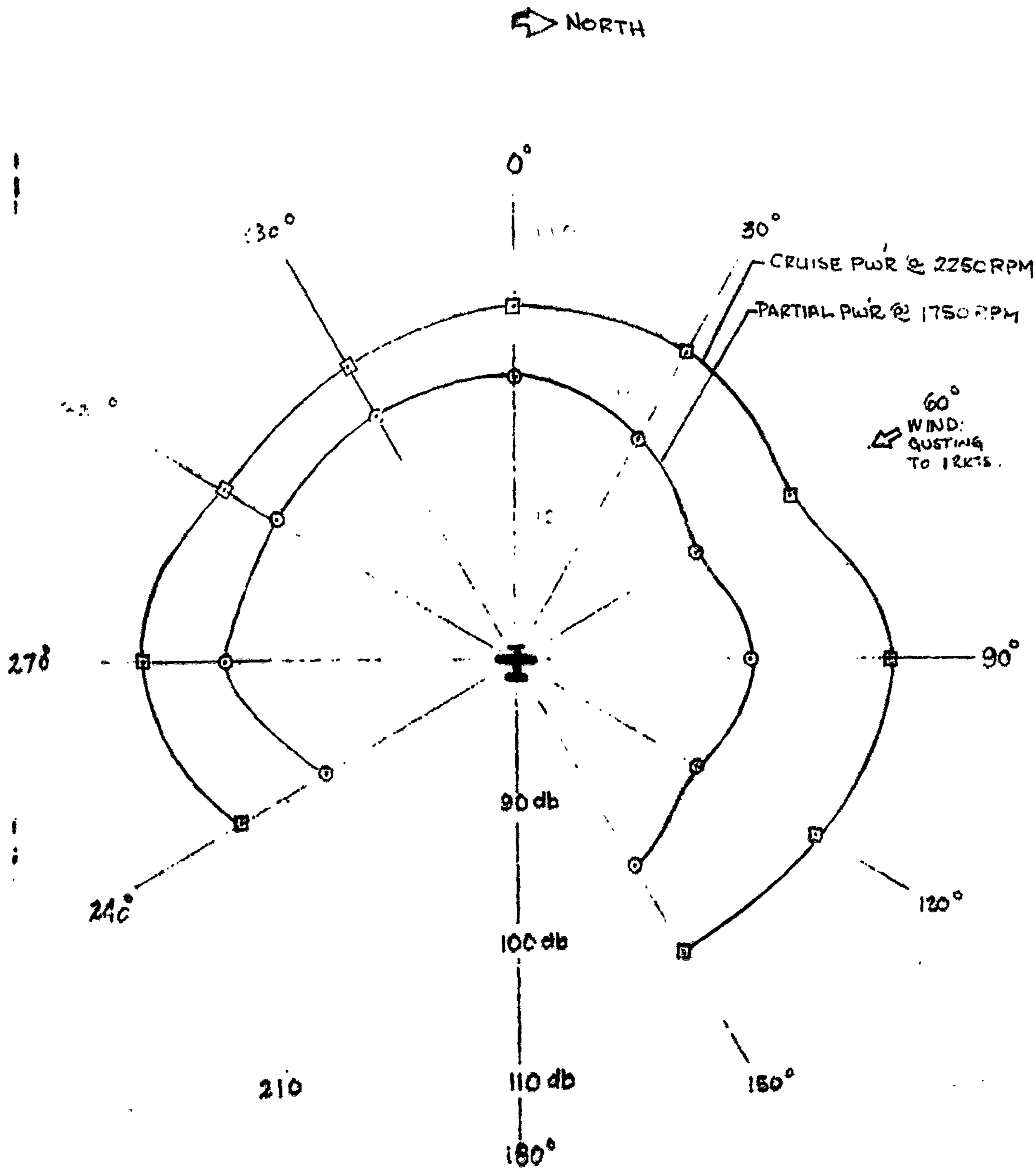


Figure 6.- Overall noise radiation pattern for O-1A aircraft during ground operation at two engine speeds. Data were measured on a 50-foot radius.

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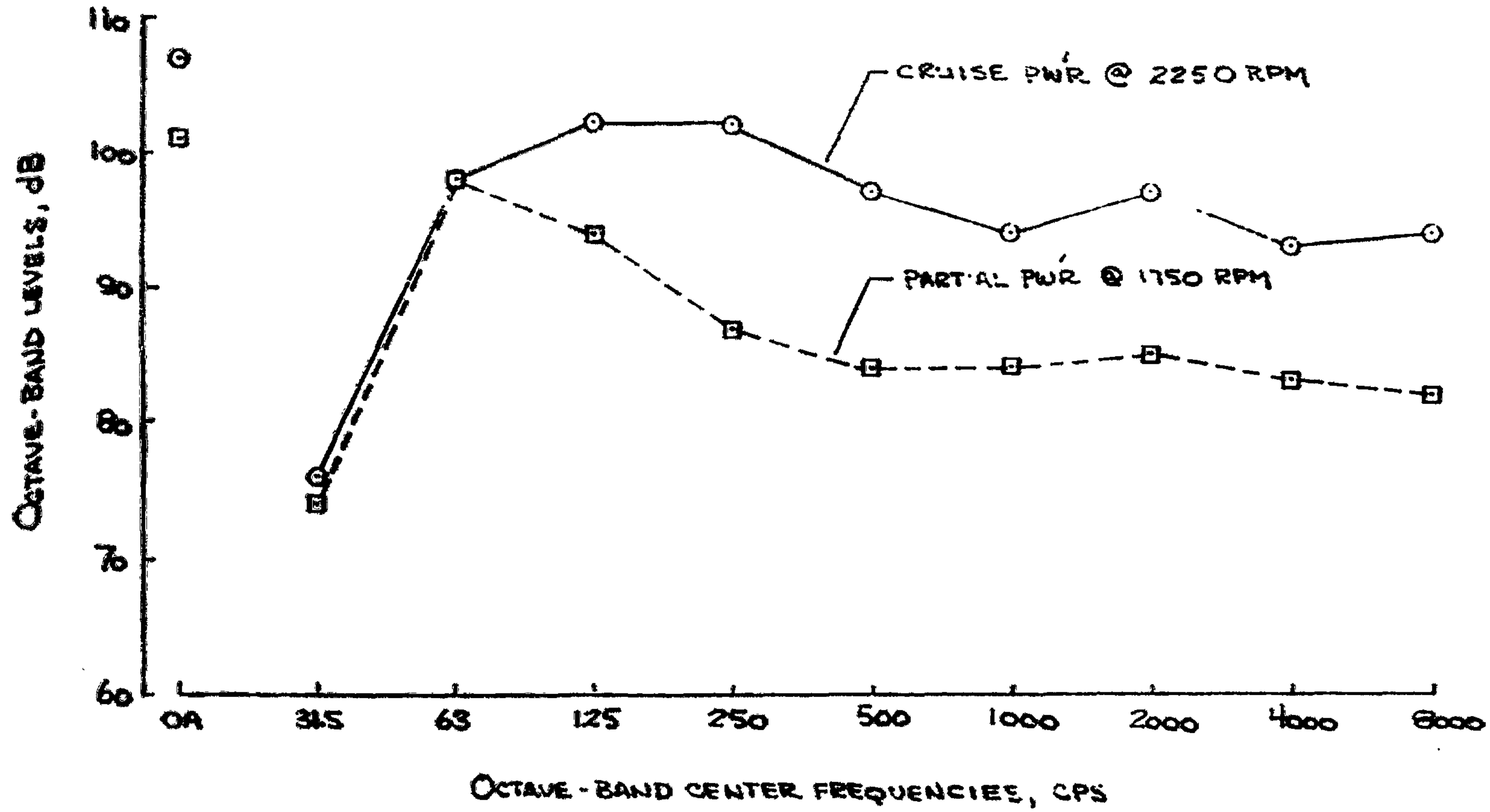


Figure 7.- Octave band spectra of noise from O-1A aircraft during ground operation at two engine speeds. Data were measured on a 50-foot radius at 90° azimuth location. (i.e. plane of propeller)

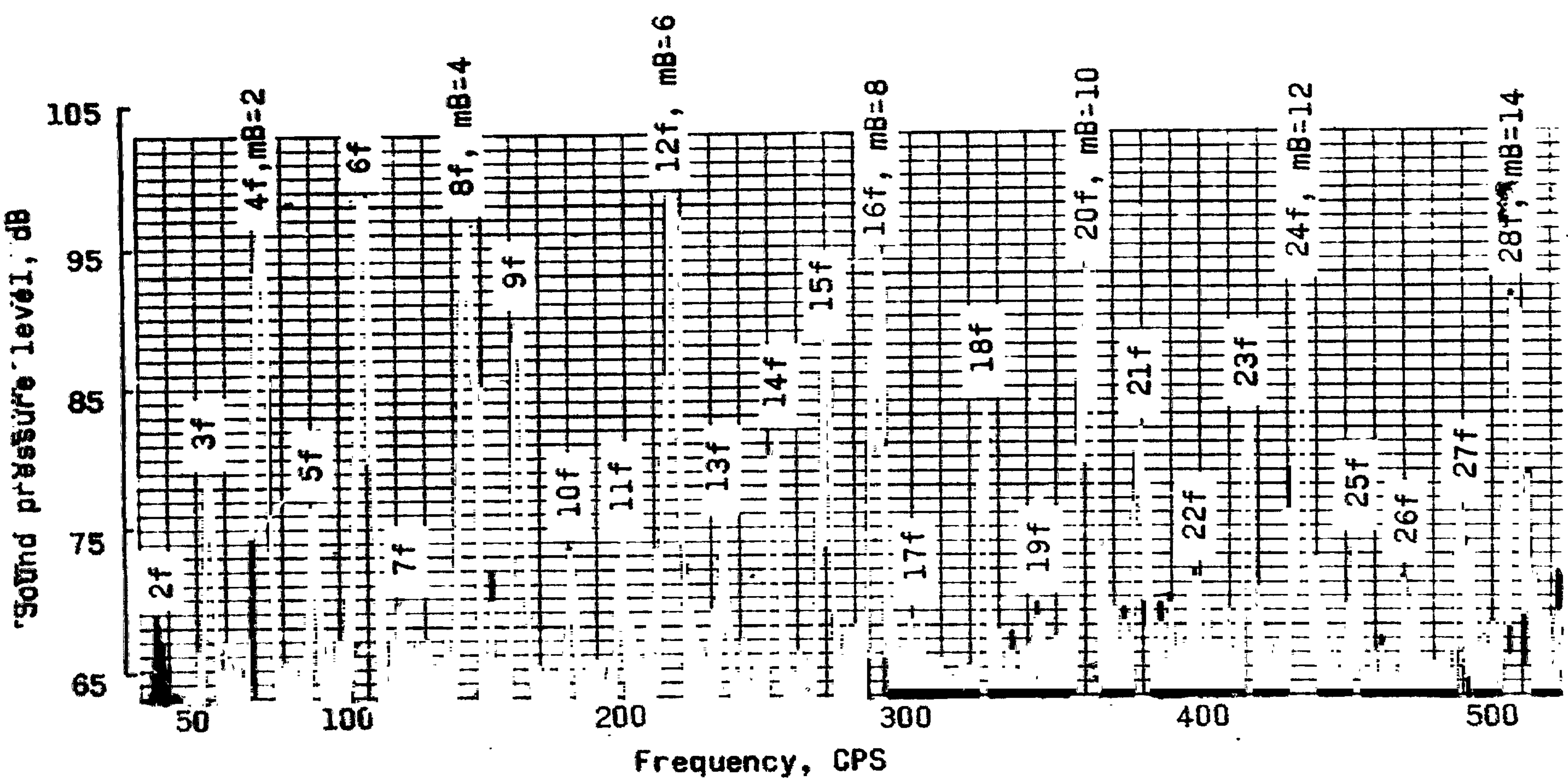


Figure 8.- Sample narrow-band analysis of airplane noise. Unmodified airplane; engine speed, N = 2200 rpm; azimuth angle $\psi = 90^{\circ}$; distance l = 50 ft; filter-band width = 3 cps.

FLT. No.	A/C OPERATING COND.			
	PWR	RPM	VEL. MPH	ALT. FT.
2	PARTIAL	1750	60	550
4	CRUISE	2250	105	590
9	IDLE	800	70	300

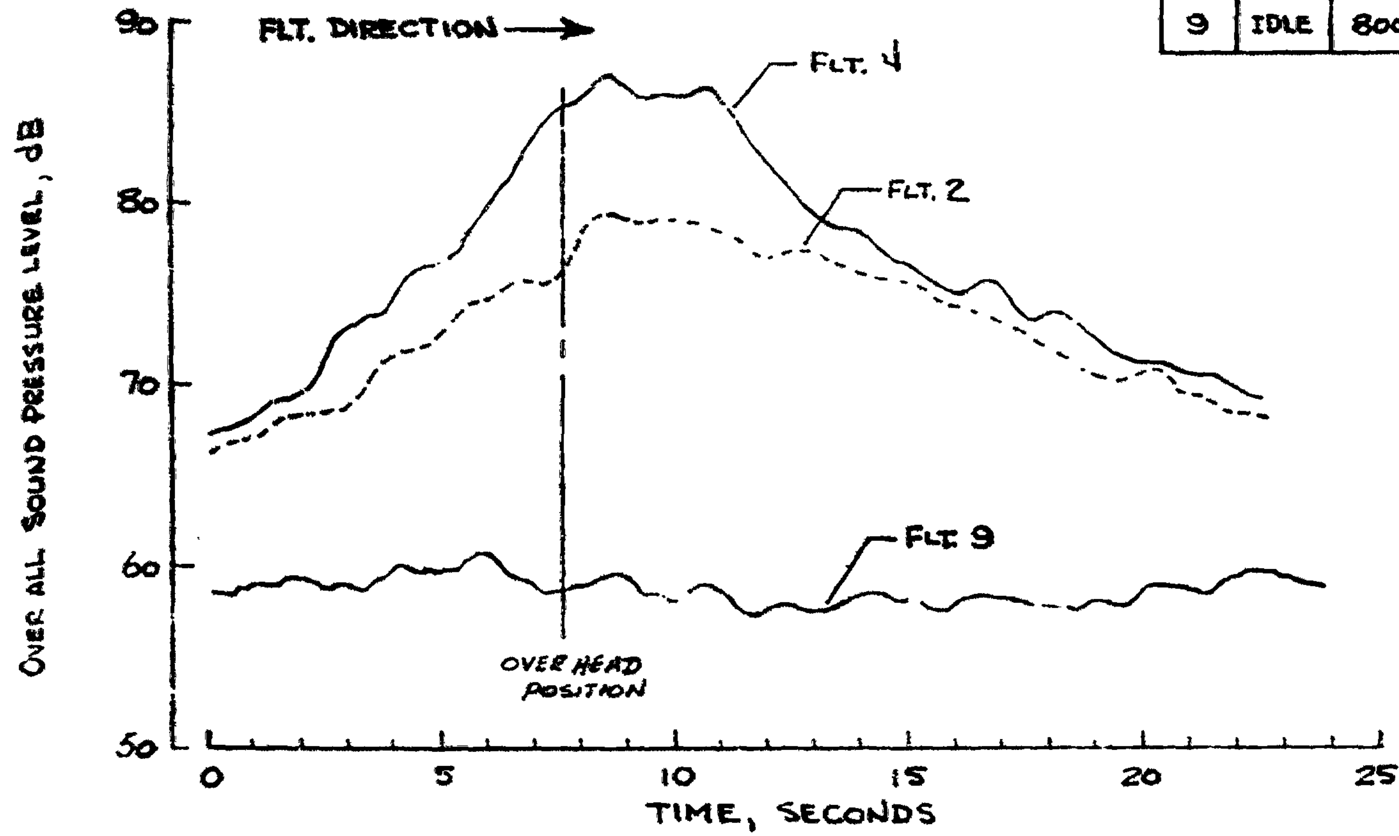


Figure 9.- Overall sound pressure level time histories for O-1A aircraft during flyby tests for three power conditions.

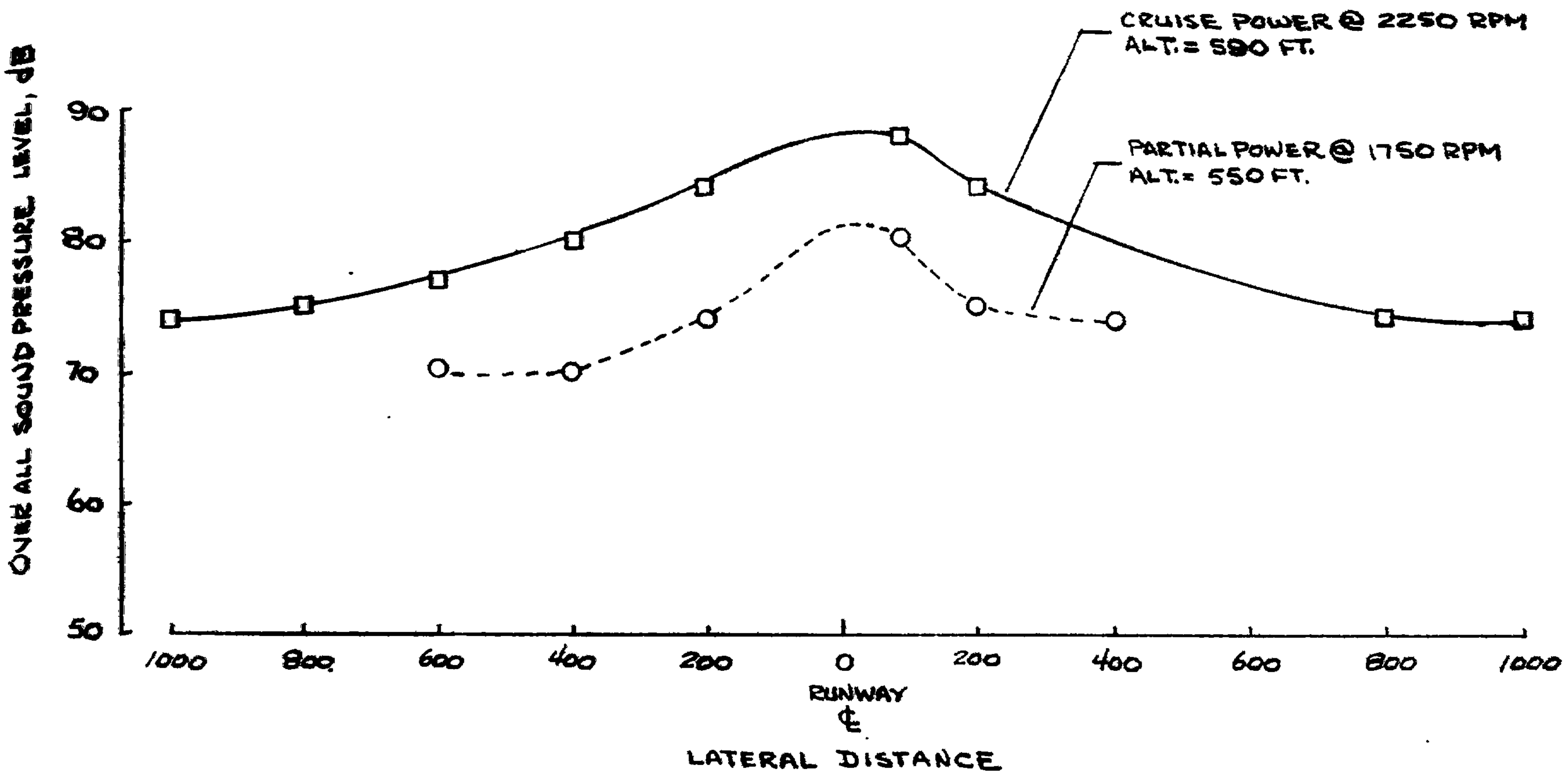
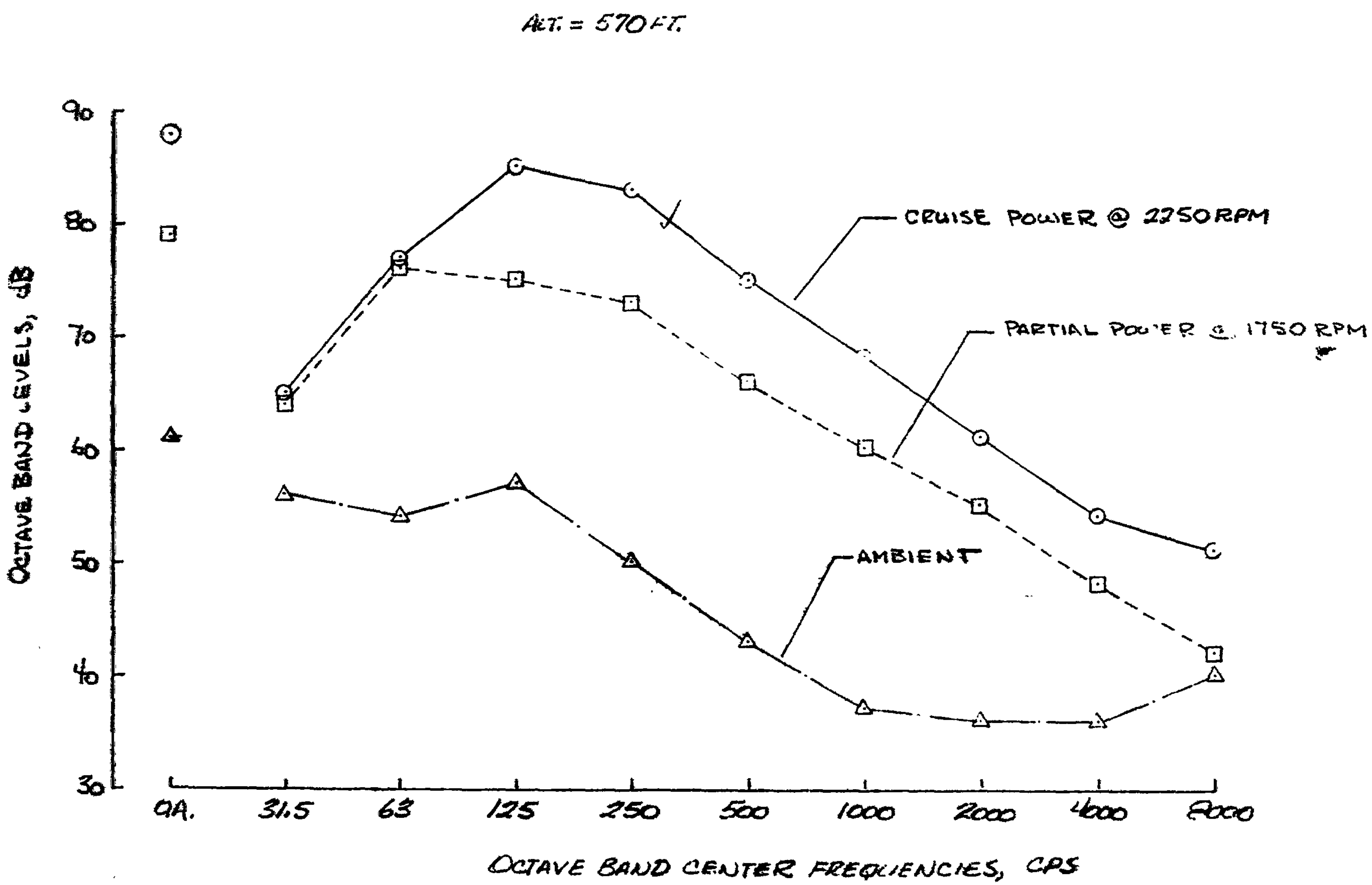
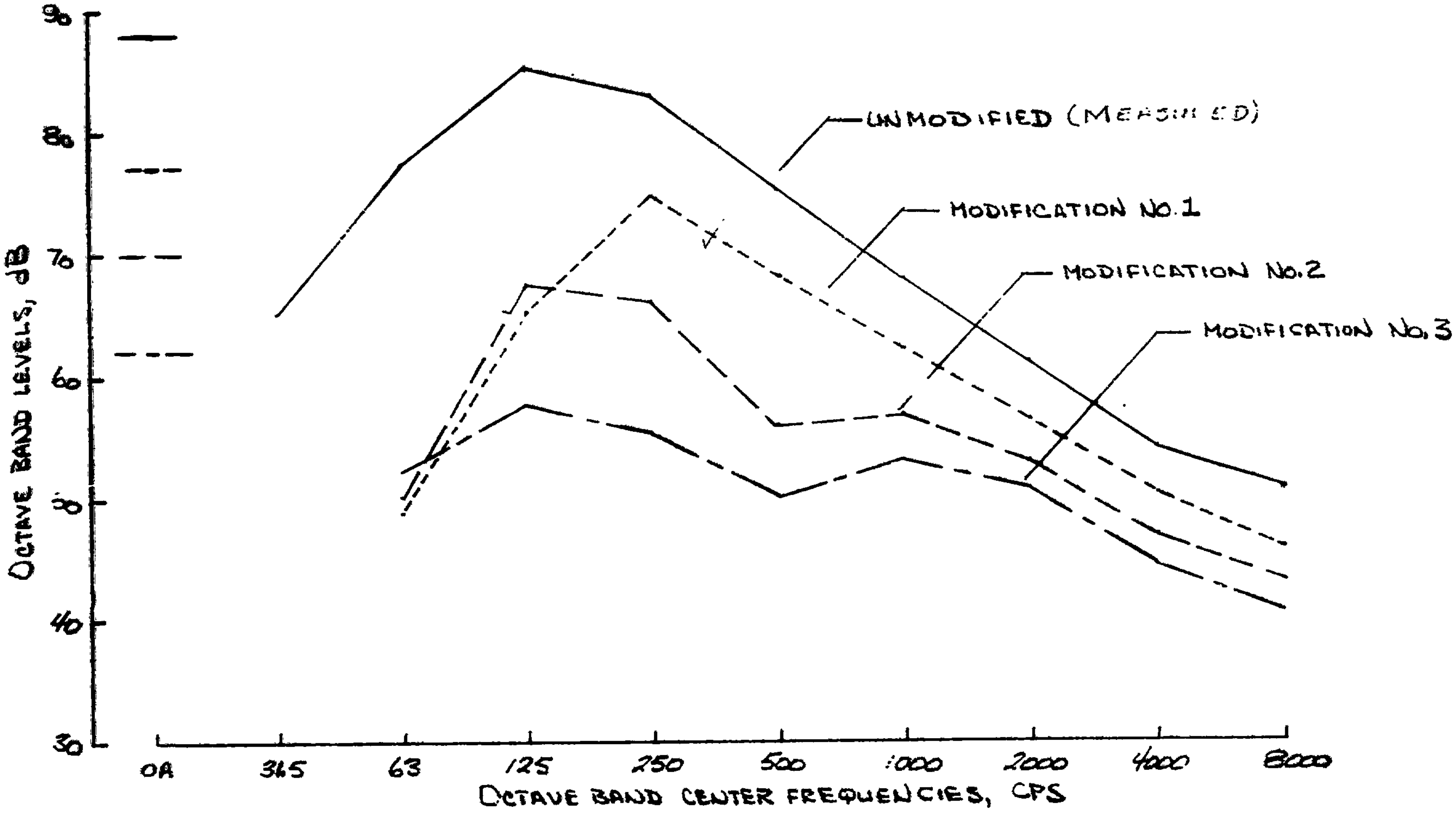


Figure 10.- Measured overall sound pressure levels as a function of distance to each side of aircraft ground track for O-1A aircraft in flight at two power conditions.



* Figure 11.- Octave band spectra of the noise on the ground track from the O-1A aircraft in flight at two power conditions. (The levels in each octave band are the maximum measured regardless of when they occur.)



* Figure 12.- Estimated octave band noise spectra for each of the three proposed modifications to the O-1A aircraft compared to the measured spectra for the basic aircraft. Data are for a distance of 570 feet.

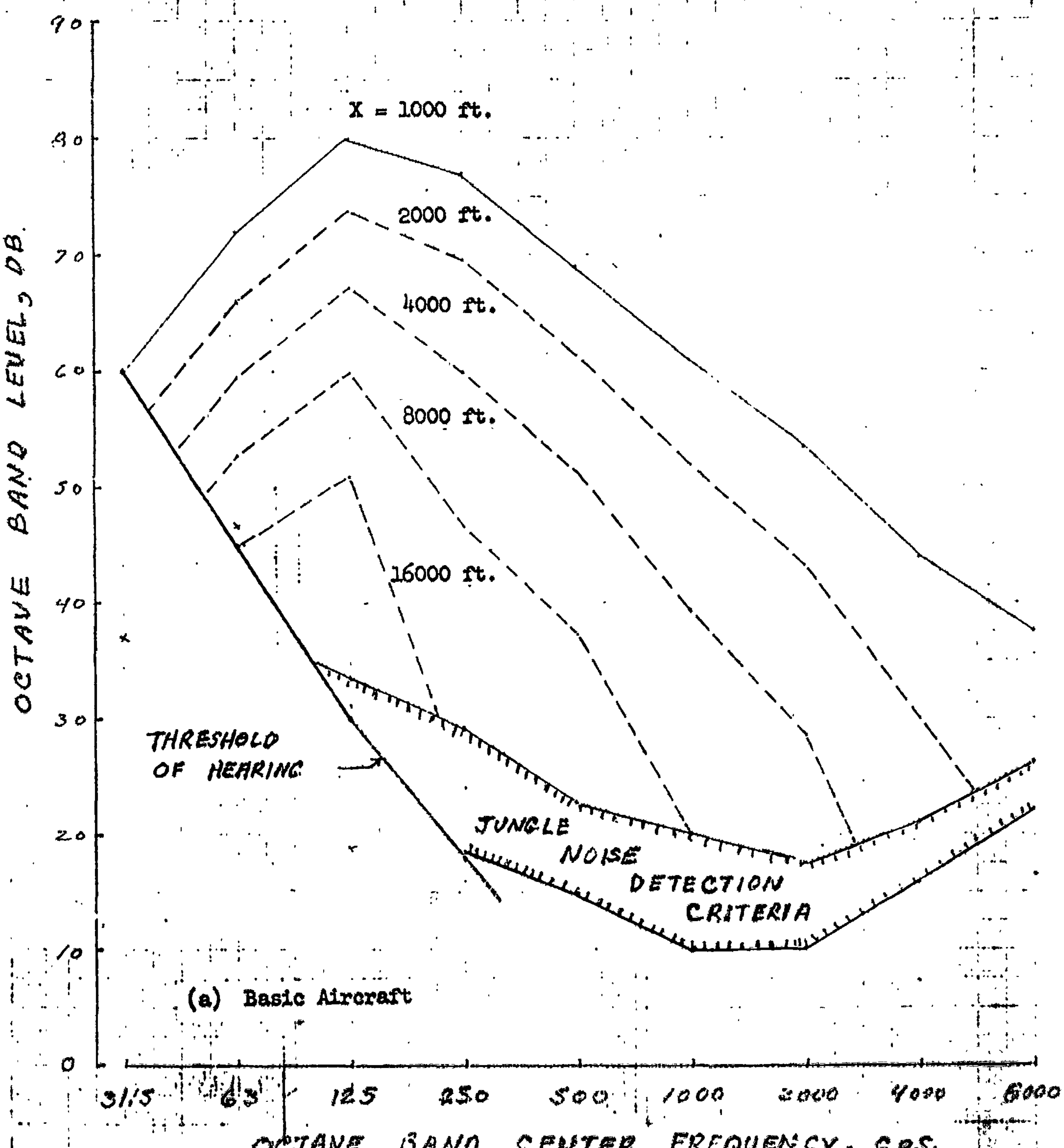


Figure 13.- Estimated noise spectra for basic O-1A aircraft and for three proposed modifications for various slant range distances. Data are for grassy (18-in. high) ground cover conditions and for an aircraft altitude of 1000 ft.

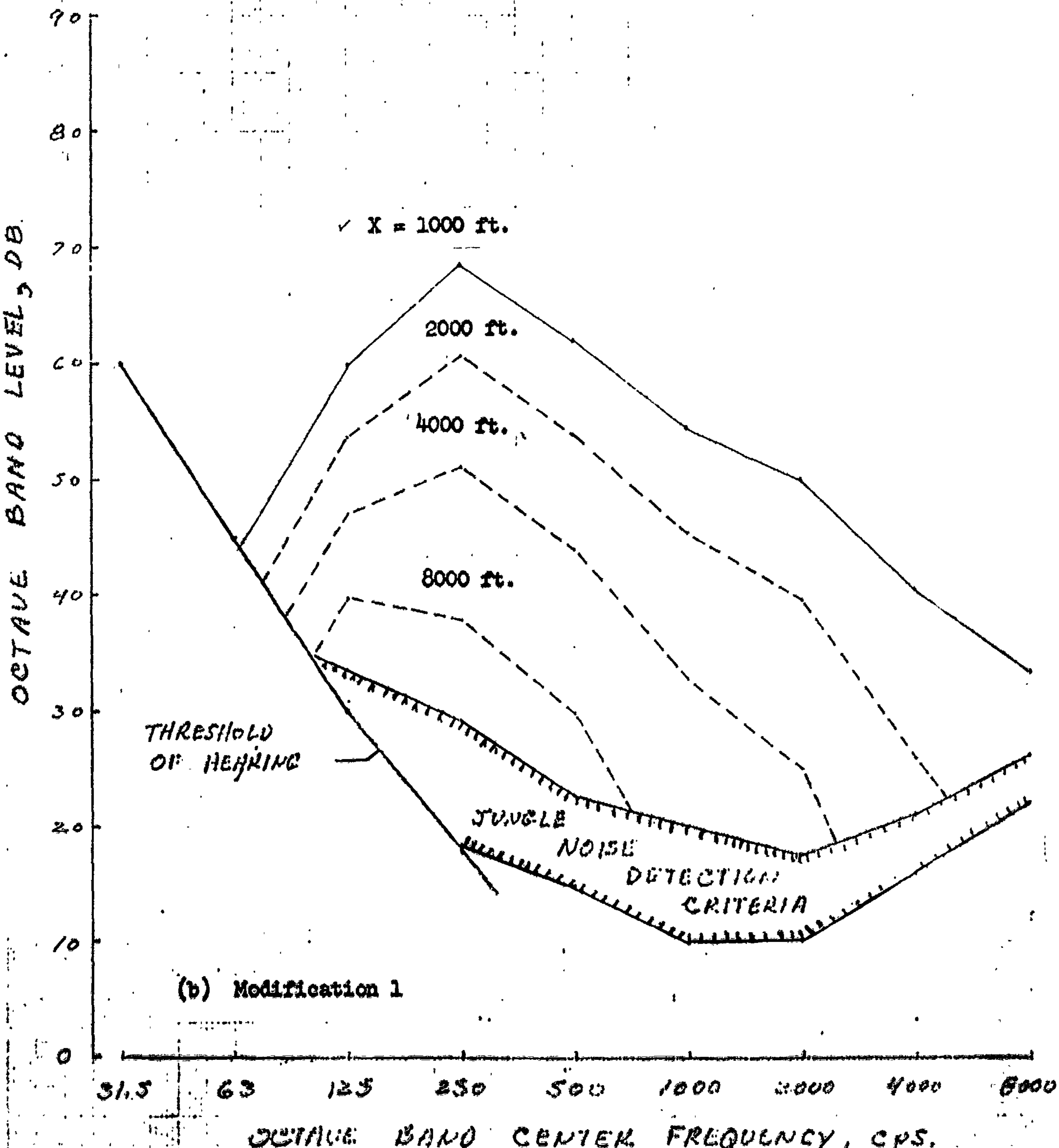


Figure 13.- Continued

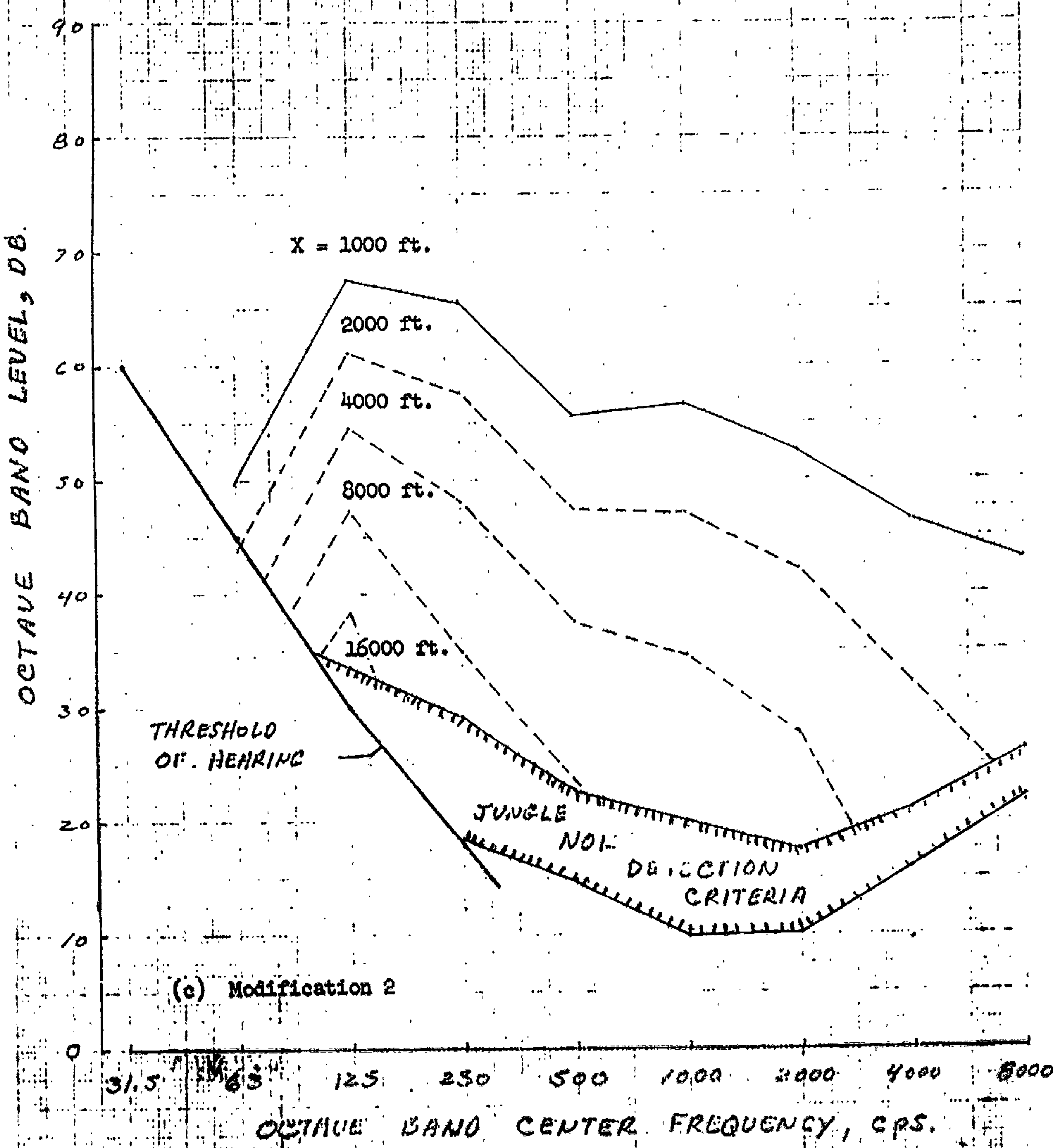


Figure 13.- Continued

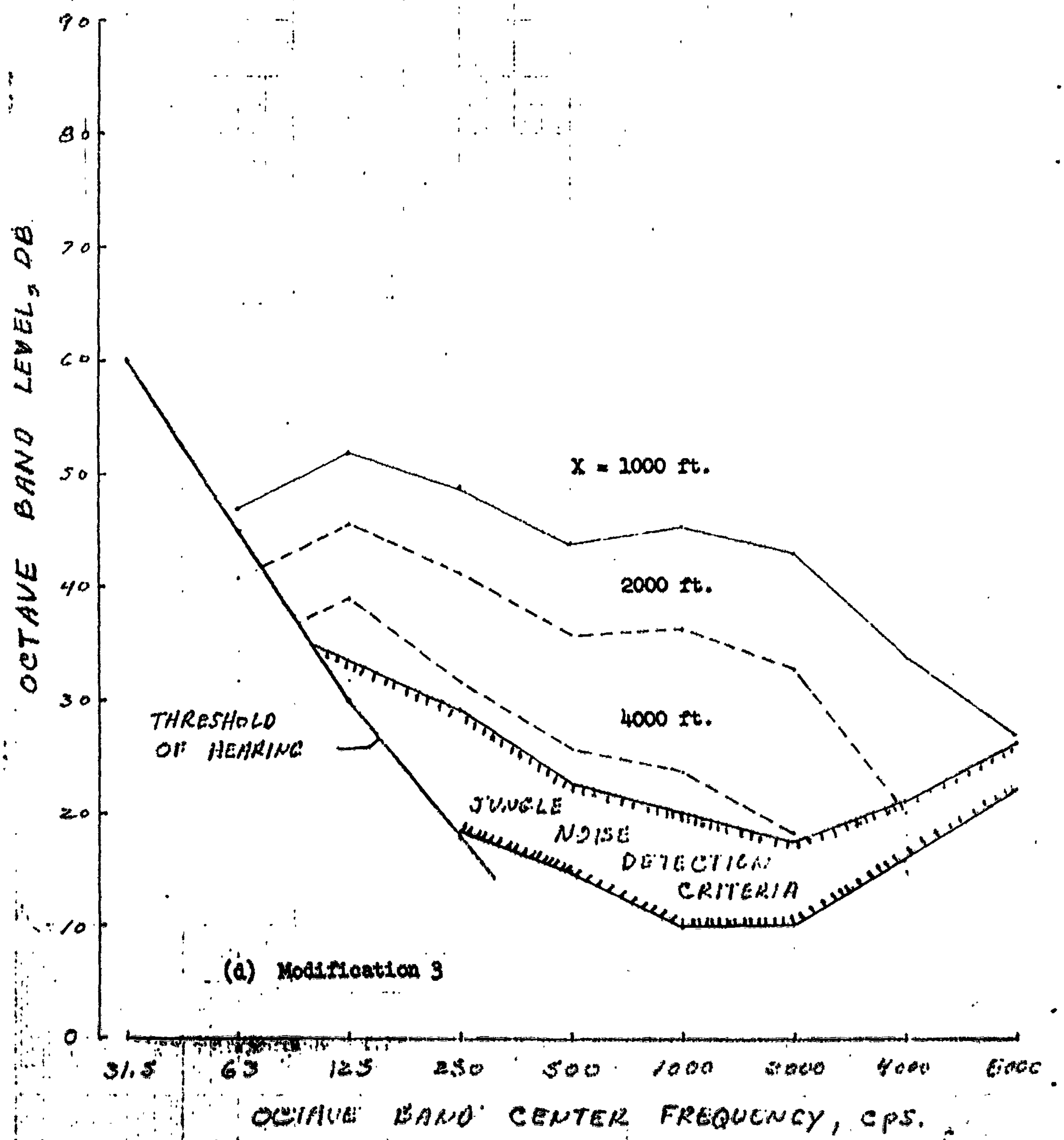


Figure 13.- Concluded.

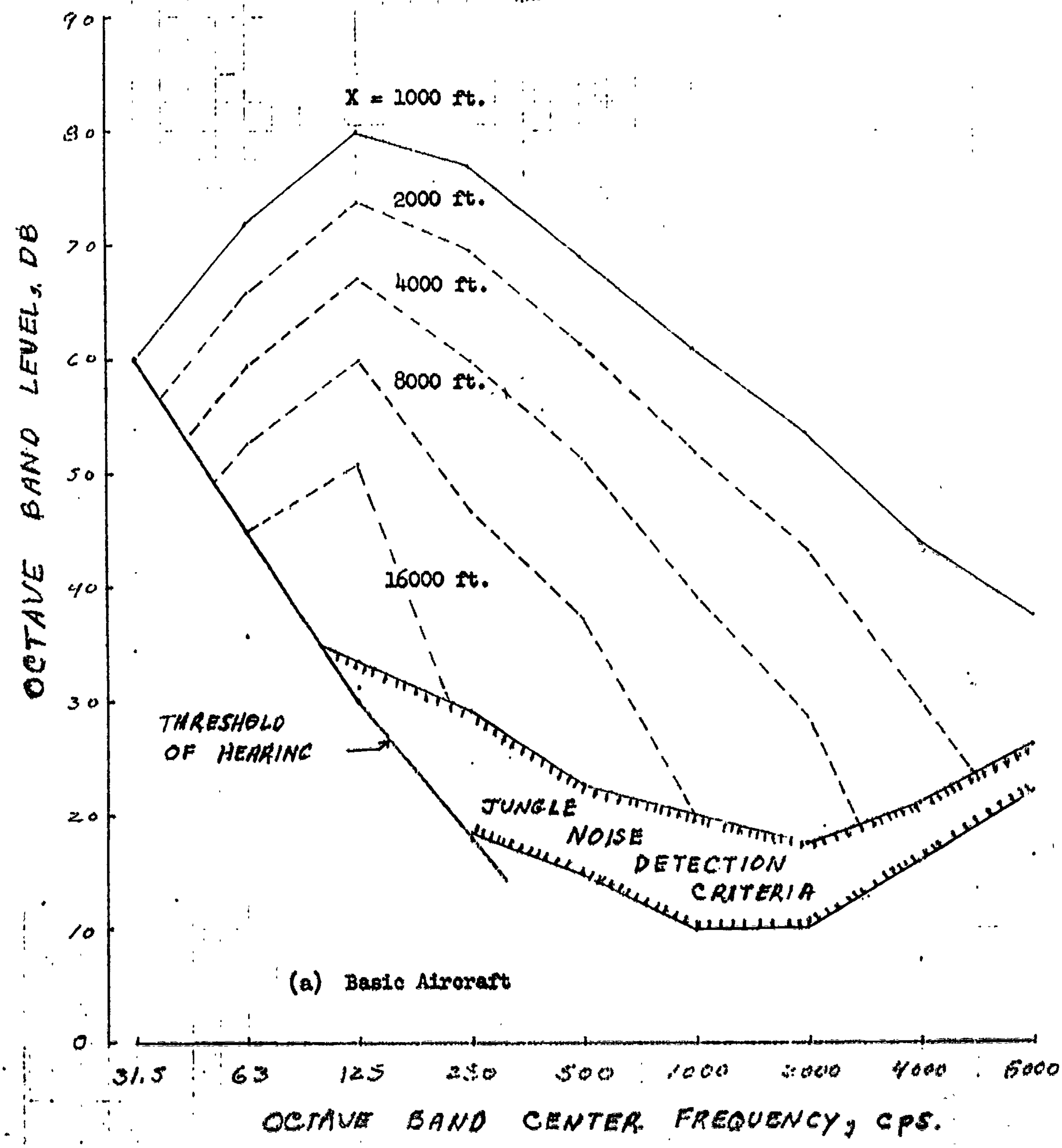


Figure 14. - Estimated noise spectra for basic O-1A aircraft and for three proposed modifications for various slant range distances. Data are for leafy jungle conditions with approximately 100 ft. see-through visibility and for an aircraft altitude of 1000 ft.

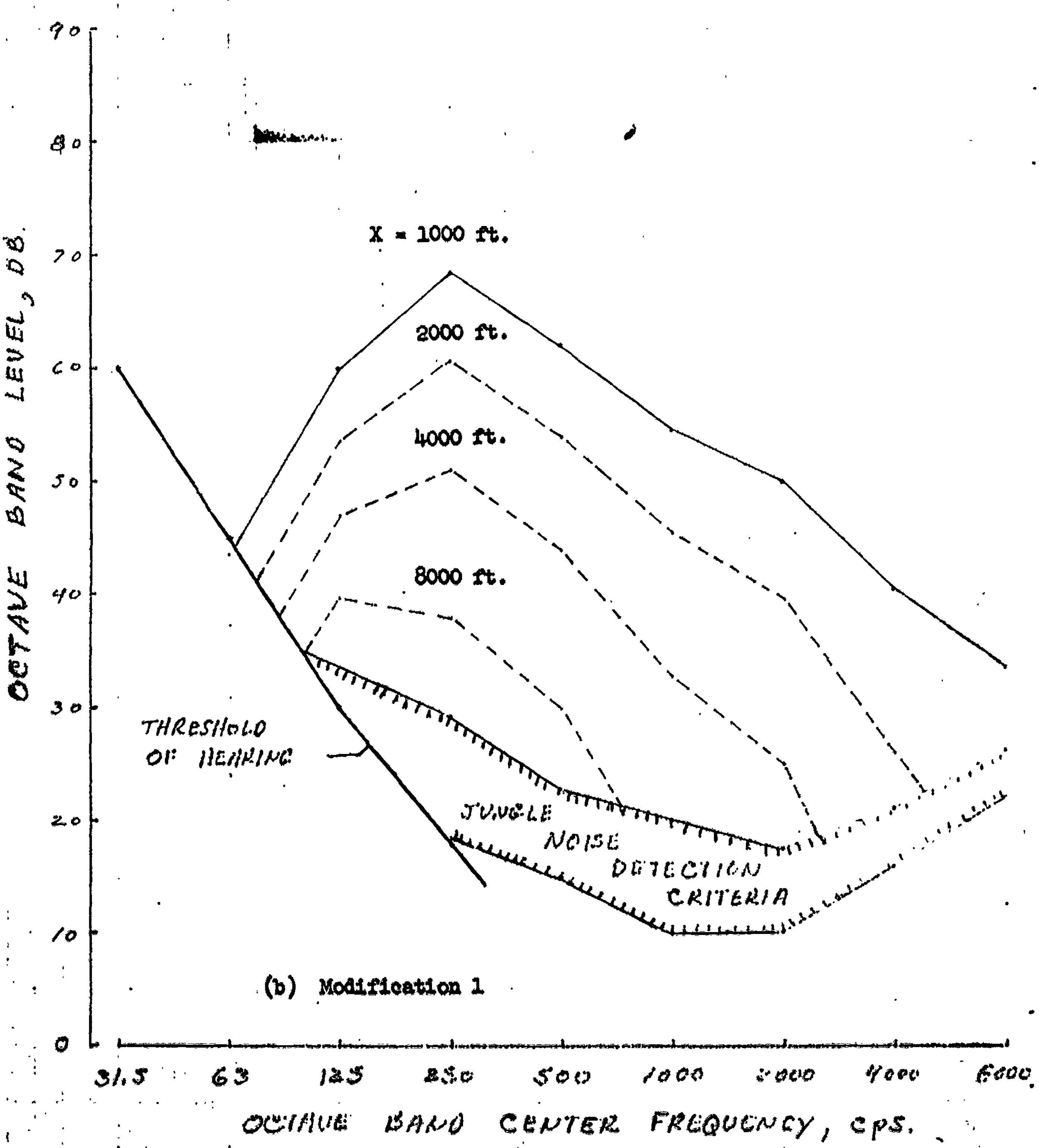


Figure 14.- Continued.

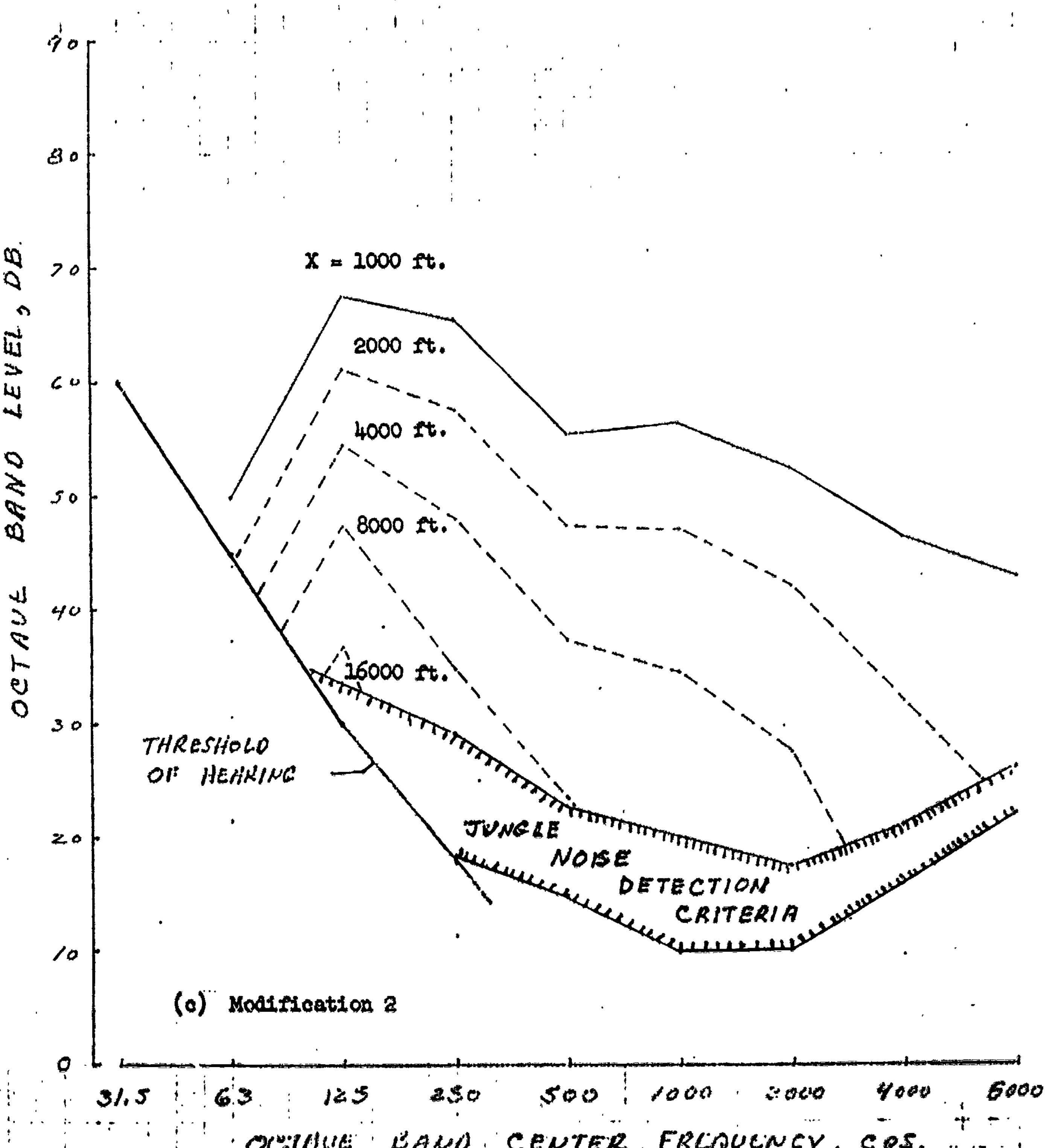
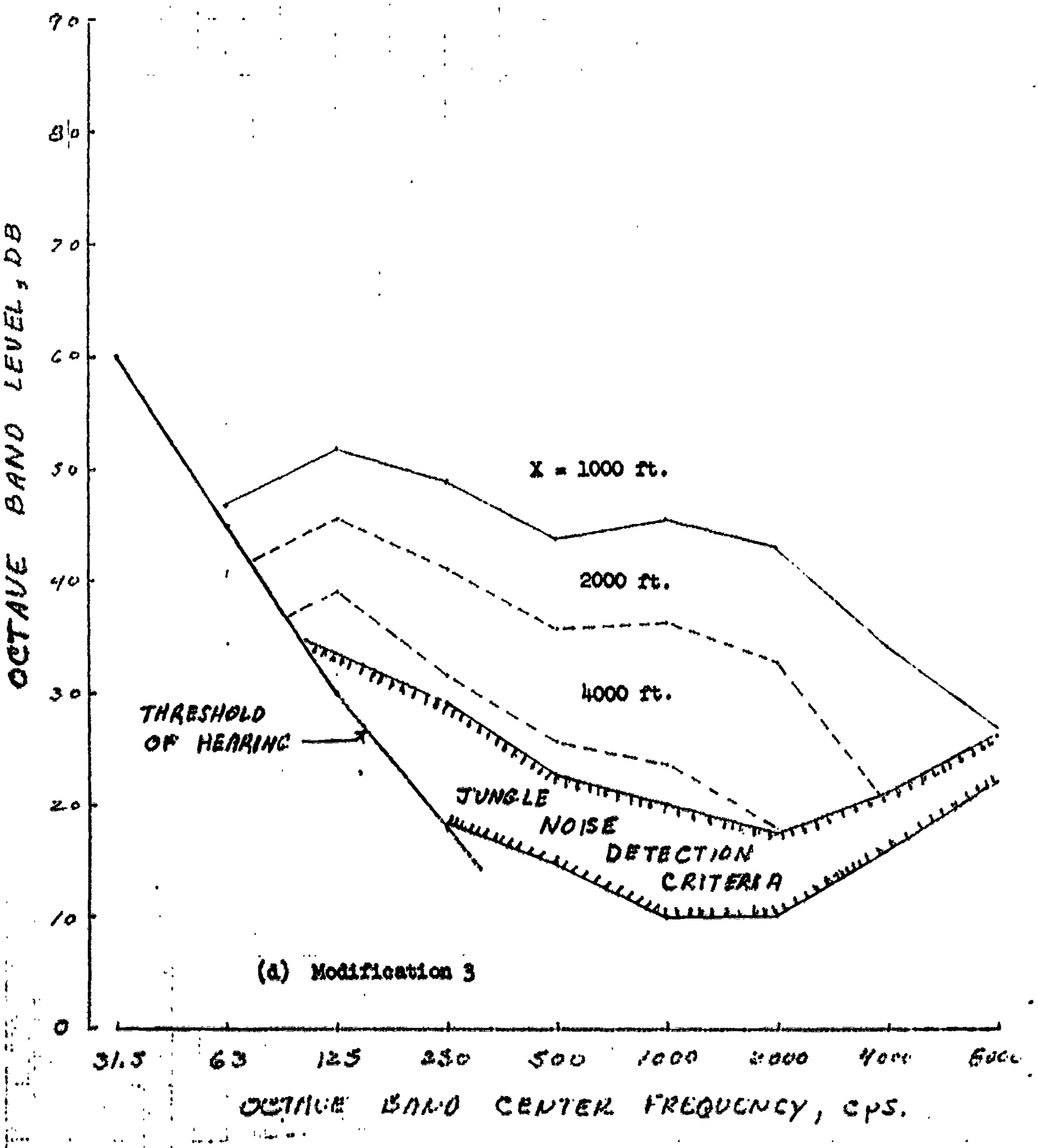


Figure 14.- Continued



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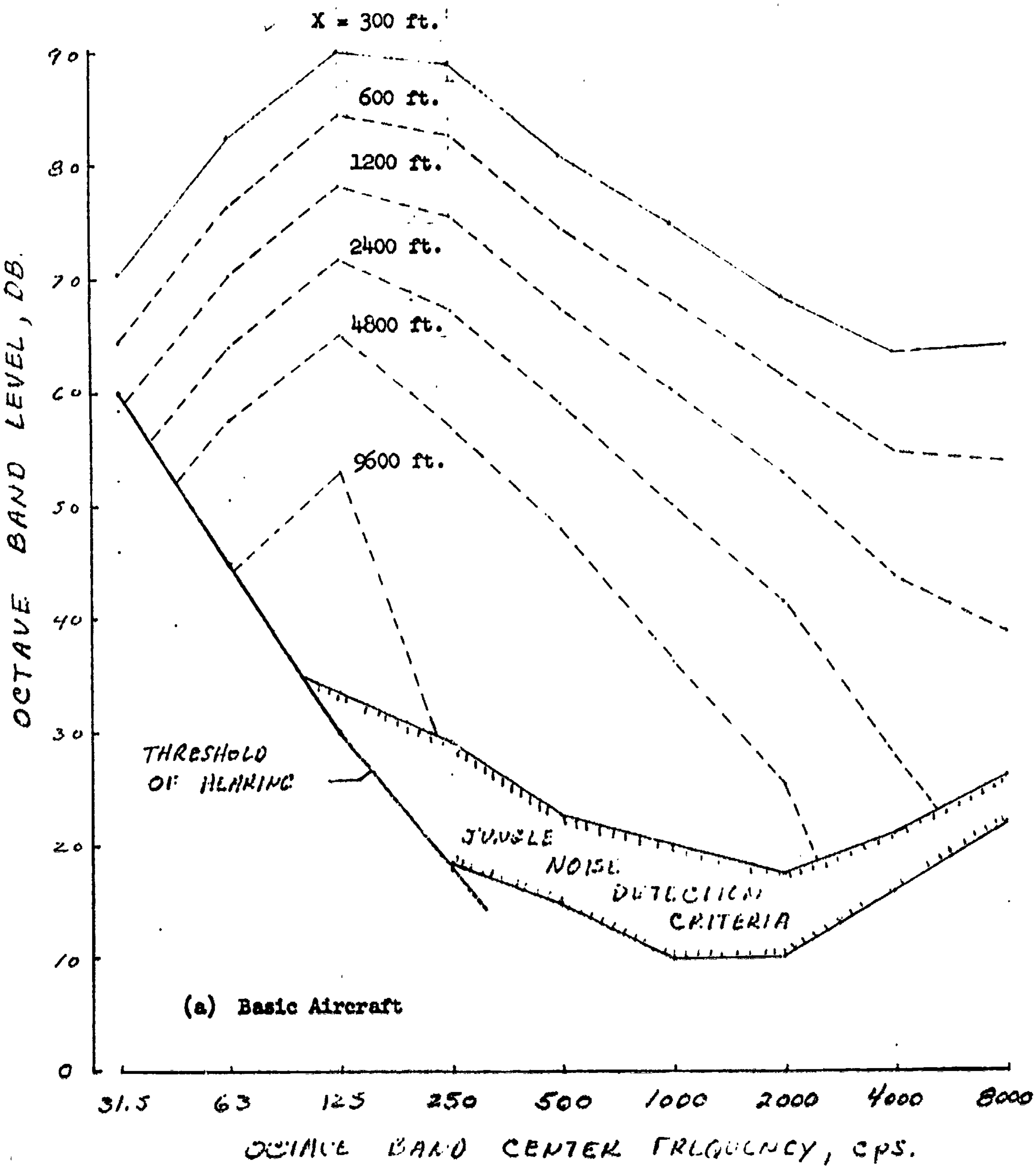
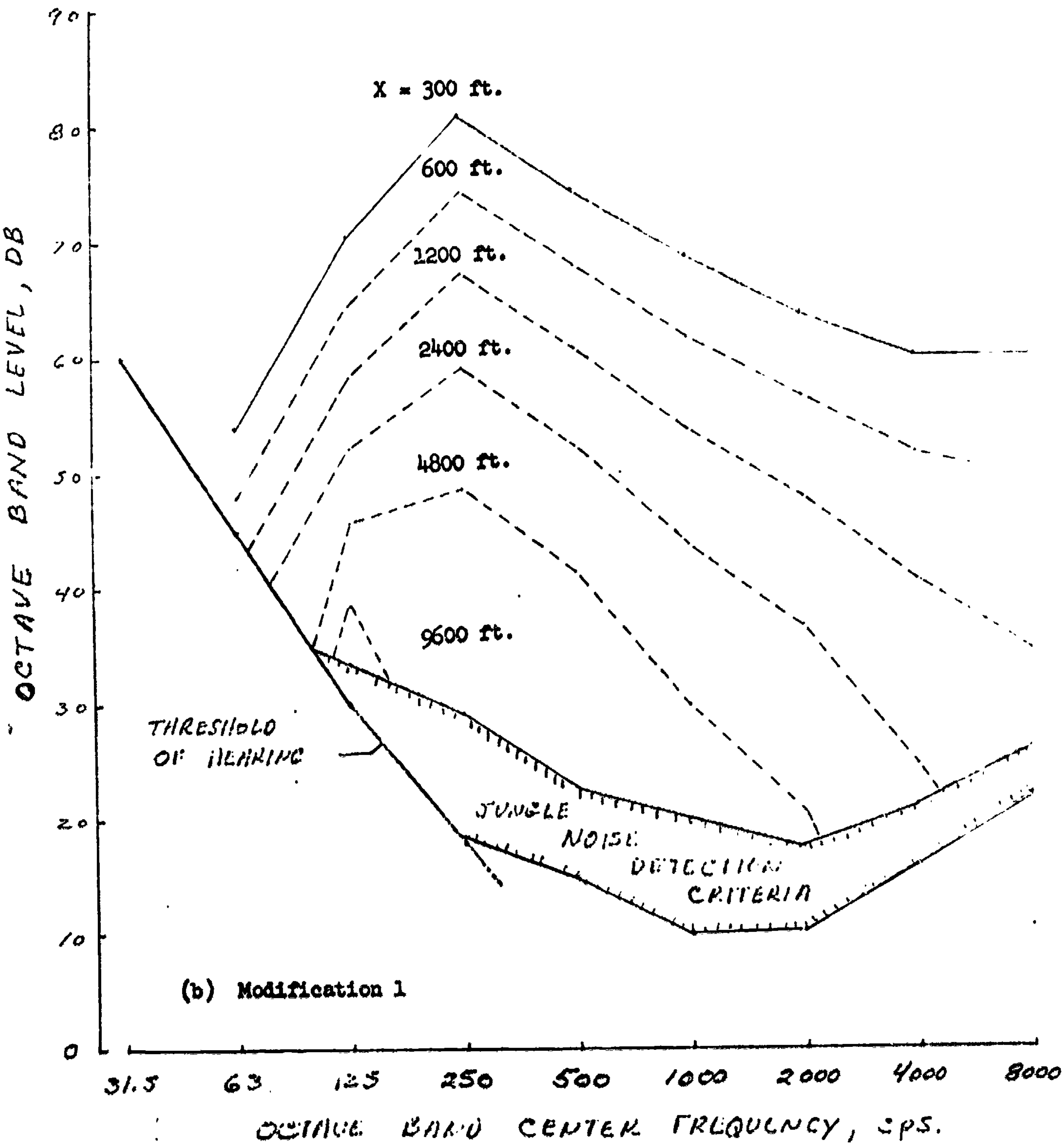


Figure 15. - Estimated noise spectra for basic O-1A aircraft and for three proposed modifications for various slant range distances. Data are for grassy (18-in. high) ground cover conditions and for an aircraft altitude of 300 ft.



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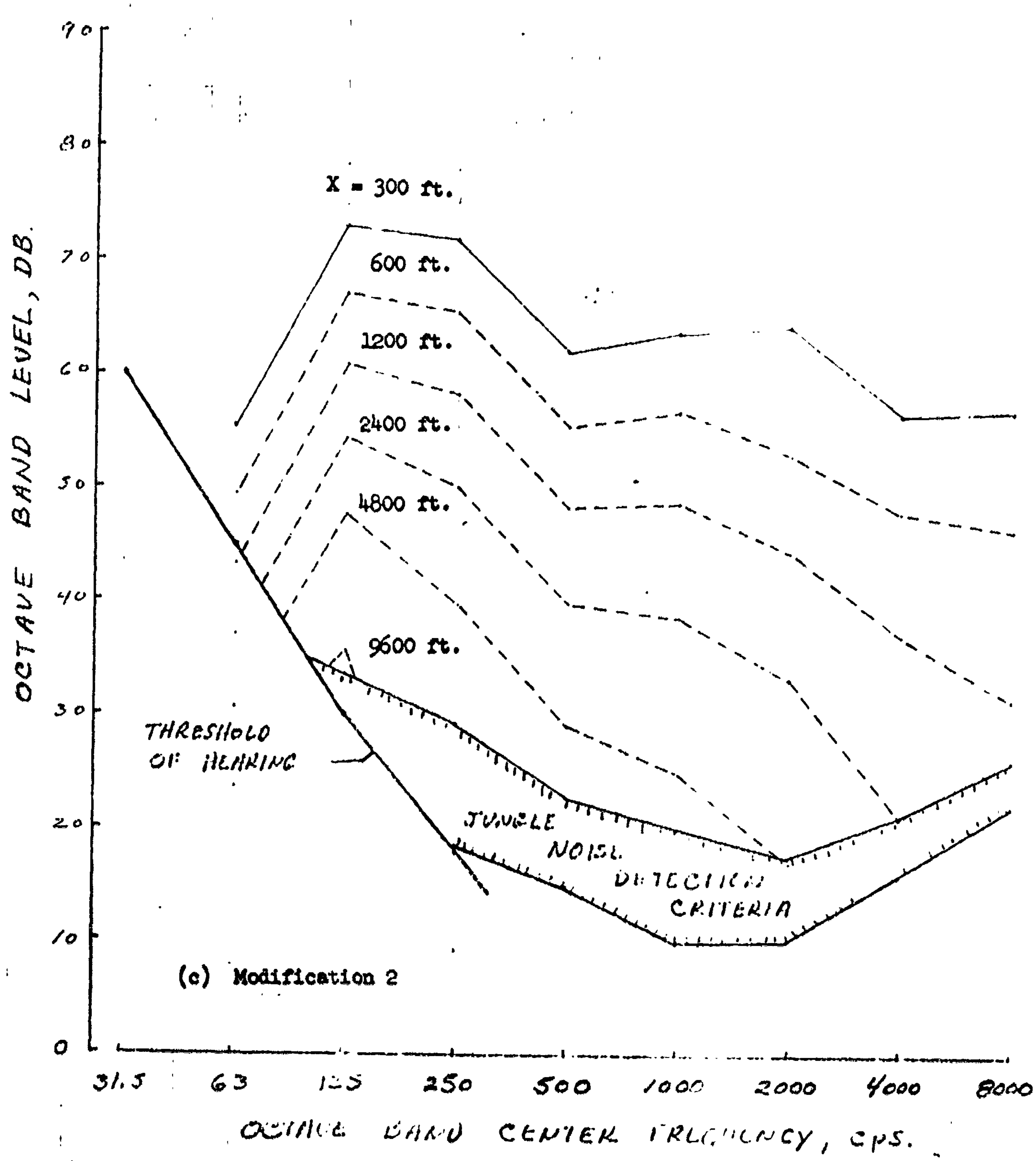

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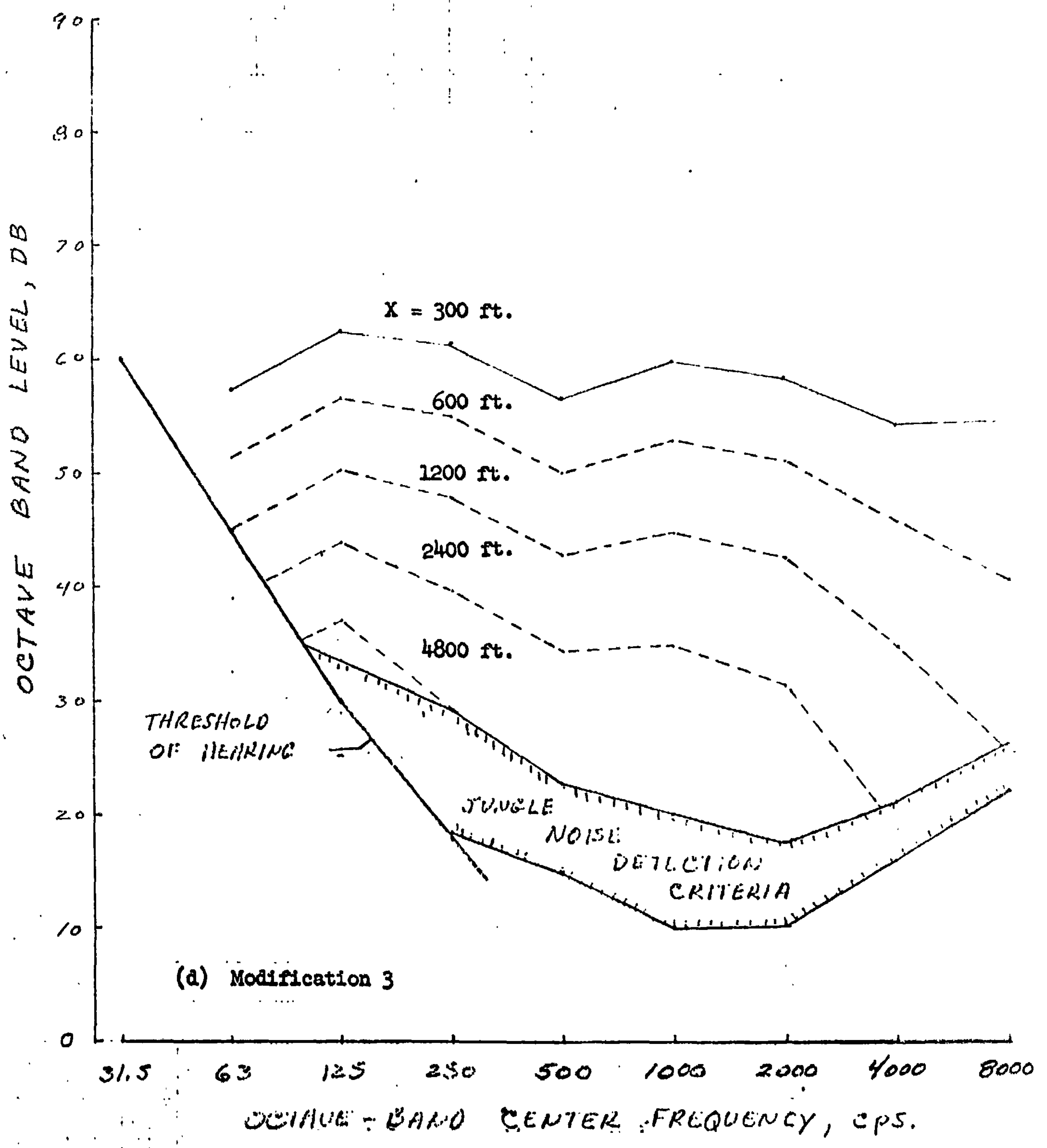

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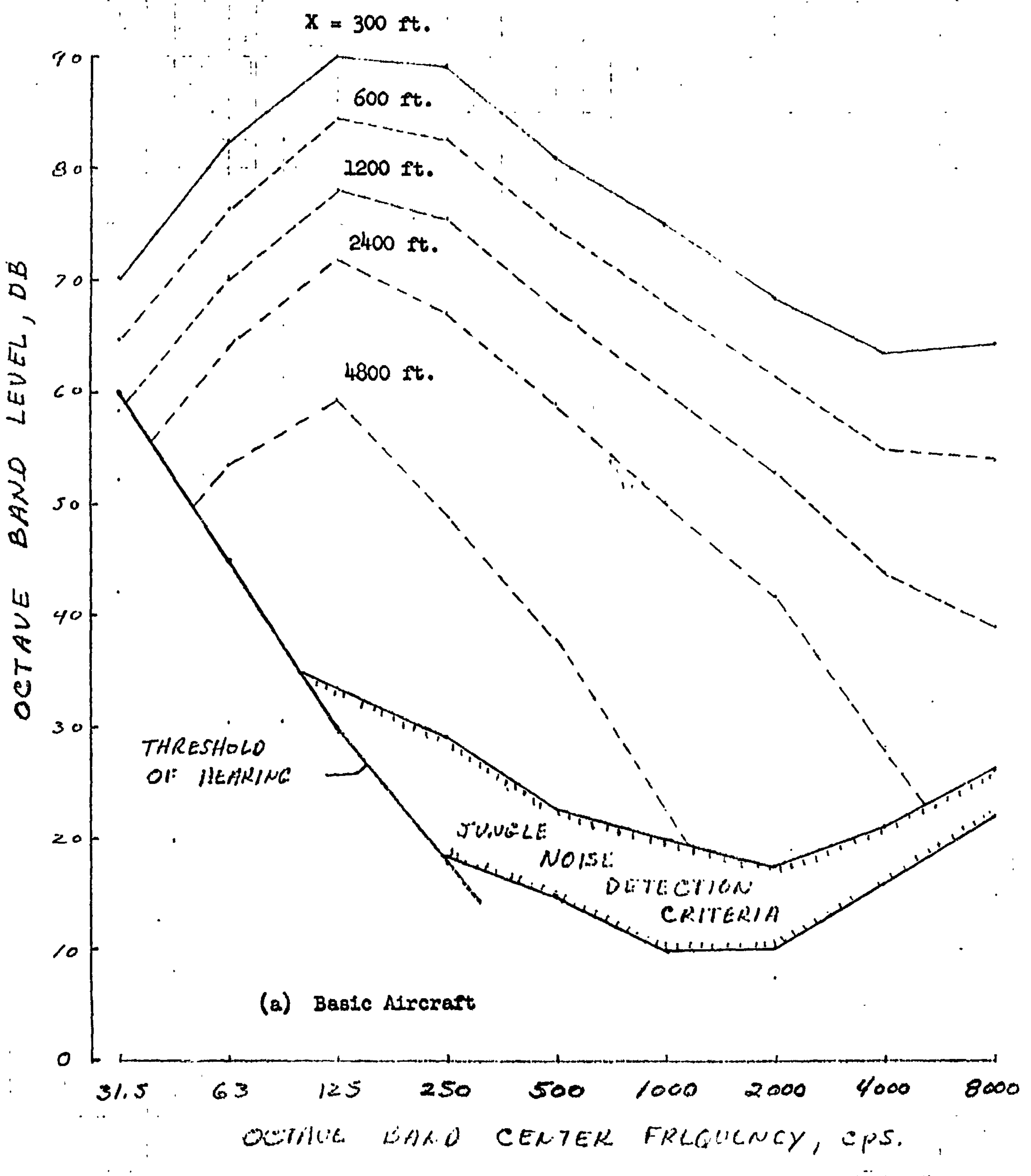

Figure 16.- Estimated noise spectra for basic O-1A aircraft and for three proposed modifications for various slant range distances. Data are for leafy jungle conditions with approximately 100 ft. see-through visibility and for an aircraft altitude of 300 ft.

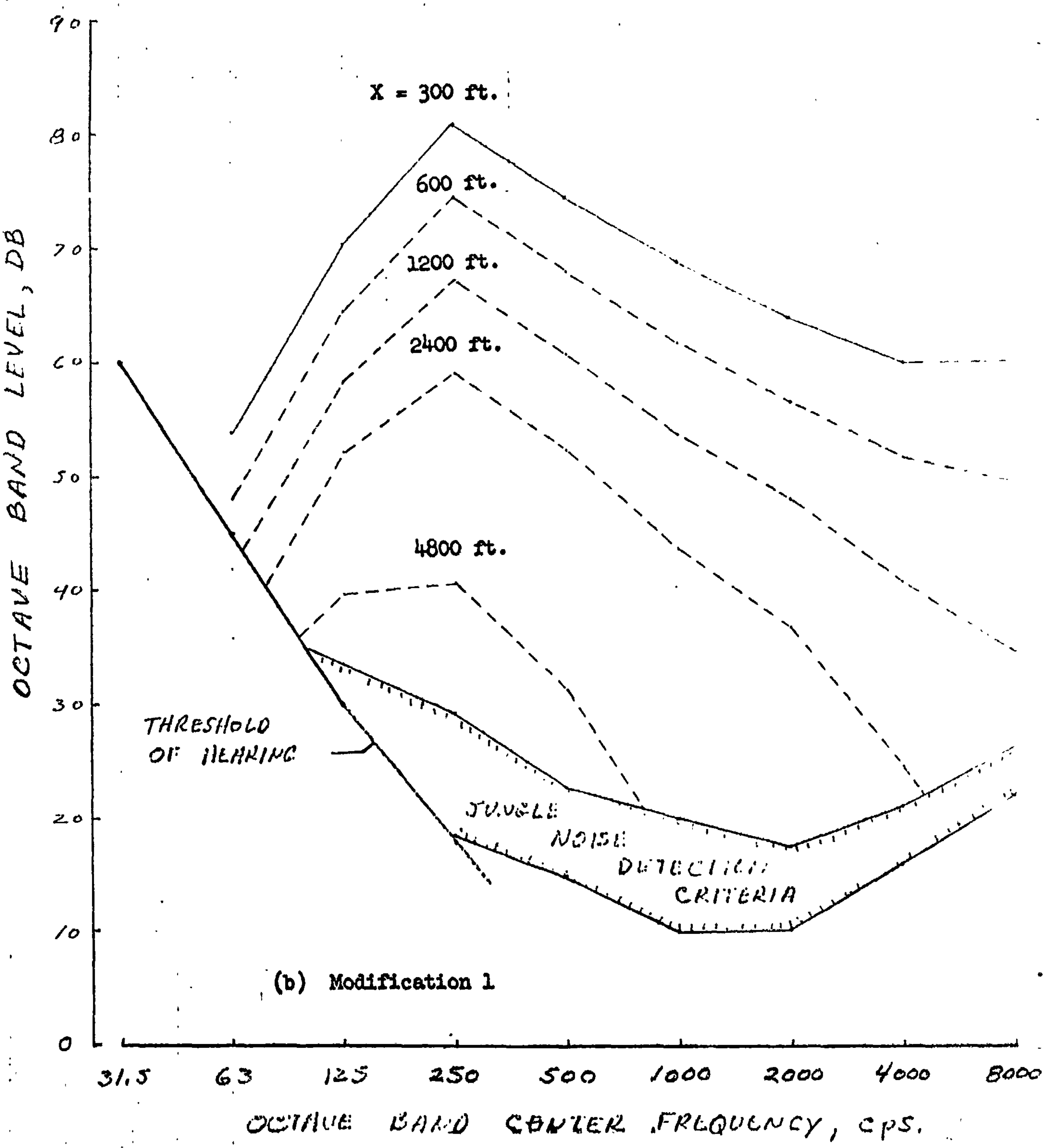

Figure 16.- Continued

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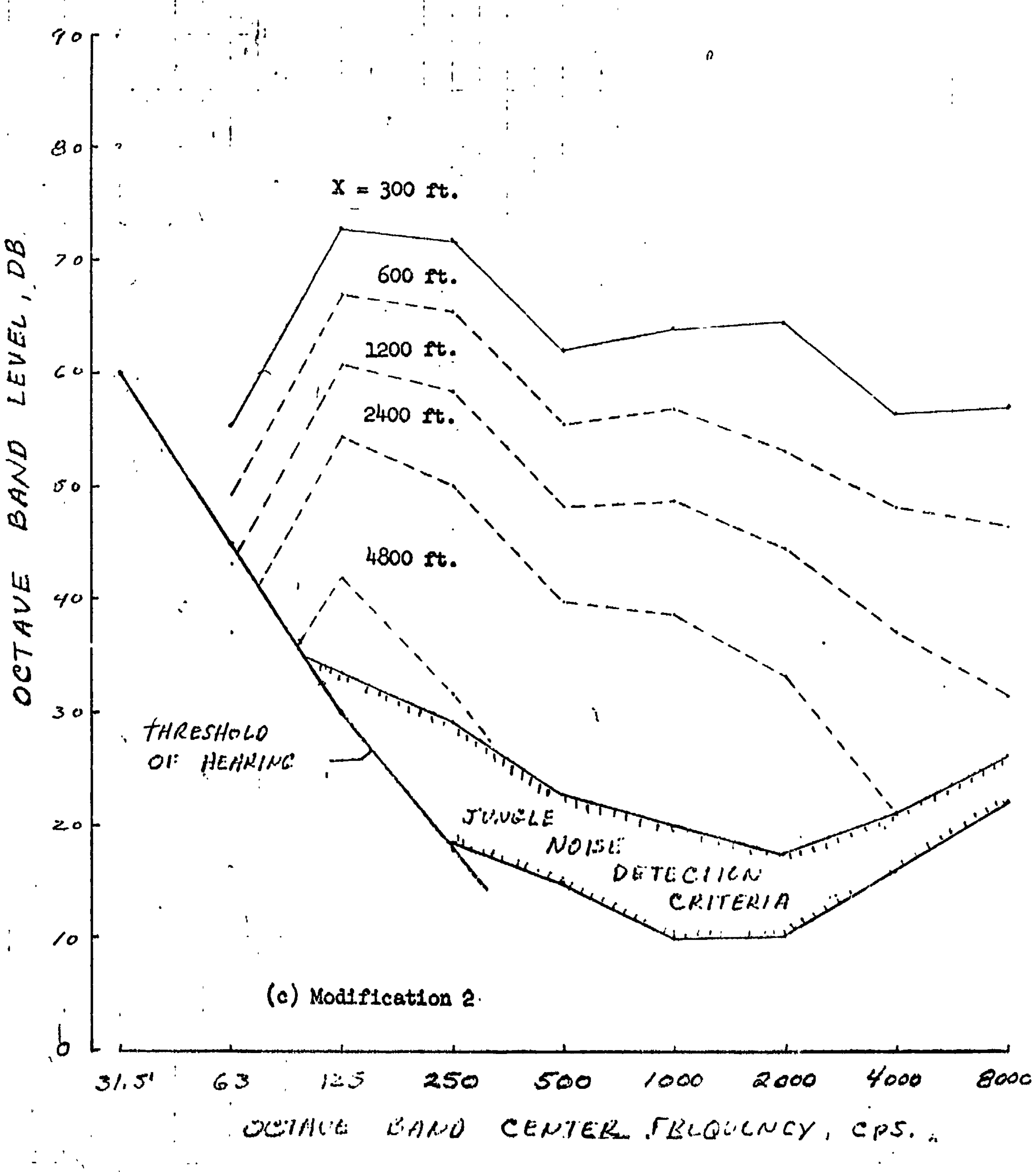


Figure 16.- Continued

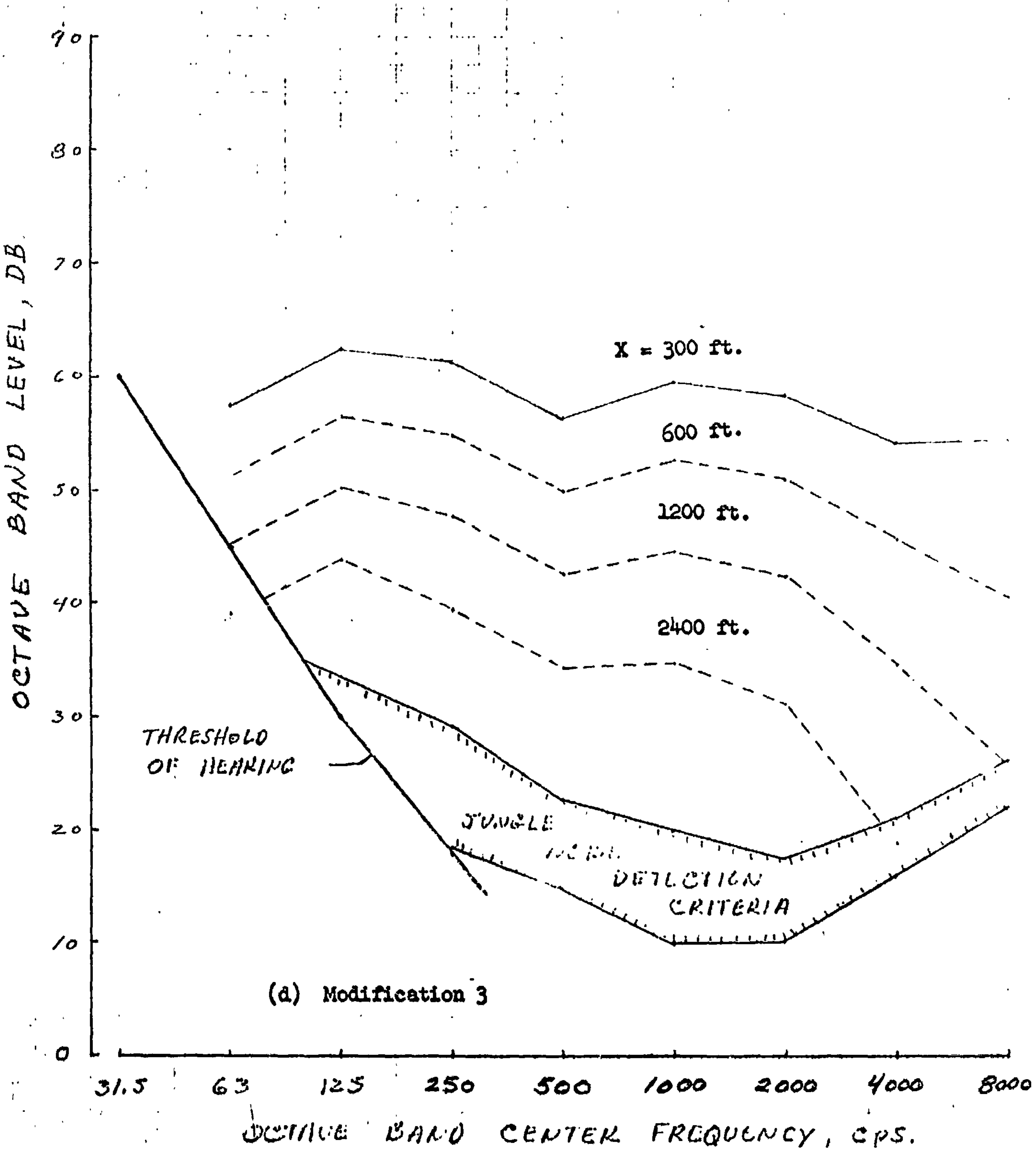


Figure 16.- Concluded

APPENDIX A

PROPELLER NOISE AND PERFORMANCE CONSIDERATIONS

John L. Crigler

For any given airplane speed and engine power, the important parameters to be considered in reducing the propeller noise are the propeller rotational tip speed and the number of blades. References A-1 and A-2 show that for a given design condition the propeller noise can be decreased by a reduction in propeller rotational tip speed, or by an increase in blade number, or b th. It becomes obvious that the two methods go together; that is, a reduction in rotational speed requires an increase in blade number to absorb the engine power.

This Appendix contains a description of the procedure used to estimate the performance of several propellers that could be fitted to the design conditions, and estimates the noise pressures generated by each propeller for the cruise (design) condition.

Propeller Selection

The basic propeller configuration on the O-1A airplane is a 7.5-ft. diameter, two-blade propeller, designed to absorb 190 hp at 2,250 engine rpm in cruise at 102 knots. For the present study it has been assumed that the maximum propeller diameter is limited to 7.5 ft. One alternate propeller design entailed a reduction in diameter to 6.5 ft. with direct drive in order to reduce the rotational tip speed, at the same time increasing the blade number to six. For two other designs involving gear reductions, propeller rotational speeds of 1,500 and 1,125 rpm were chosen.

The performance of each of the three alternate propellers has been estimated for fixed and controllable pitch operation and these data are compared with the estimated data for the basic propeller configuration in Table A-I.

Also listed in Table A-I are the number of blades and blade width required for each configuration along with the total estimated weight of the propeller.

The propeller efficiency for the design cruise conditions for each propeller was estimated by the method given in the Appendix of reference A-3. The efficiencies at best rate of blimb, taken as 58 knots, and the static thrust were obtained with the aid of references A-3, A-4, A-5, and A-6.

The propeller noise levels for all configurations were estimated for a distance of 50 ft. from the source by the method given in reference A-1 and are presented in Table A-II. An examination of the data in Table A-I and Table A-II indicates it is possible to design variable-pitch constant-speed propellers of high performance over the entire operating range which are markedly quieter than the propeller installed on the O-1A airplane.

REFERENCES

A-1. Hubbard, Harvey H.: Propeller Noise Charts for Transport Airplanes. NACA TN 2968, 1953.

A-2. Hubbard, Harvey H.; and Regier, Authur A.: Propeller-Loudness Charts for Light Airplanes. NACA TN 1358, 1947.

A-3. Crigler, John L.; and Jaquis, Robert E.: Propeller-Efficiency Charts for Light Airplanes. NACA TN 1338, 1947.

A-4. Crigler, John L.: Comparison of Calculated and Experimental Characteristics for Four, Six, and Eight Blade Single Rotating Propellers. NACA ACR No. 4B04, 1944.

A-5. Biermann, David; and Hartman, Edwin P.: Wind-Tunnel Tests of Four- and Six-Blade Single and Dual Rotating Tractor Propellers. Report No. 747, NACA, 1942.

A-6. Biermann, David, and Gray, W. H.: Wind-Tunnel Tests of Eight-Blade Single and Dual Rotating Propellers in the Tractor Position. NACA ARR., Nov. 1941.

Table A-I.- Summary of performance calculations for basic and modified propeller configurations.

Fixed Pitch Propellers

Configuration	N rpm	D	πnD	M_t	B	Blade Width	η @102 Kt	η@58 Kt	Static Thrust	Weight
Basic	2250	7.5	883	.790	2	basic	.83	.65	855	46.1
Modification 1	2250	6.5	765	.685	6	.58 basic	.82	.62	768	40.1
Modification 2	1500	7.5	588	.527	5	basic	.83	.64	714	104.2
Modification 3	1125	7.5	441	.395	5	1.60 basic	.83	.61	550	204.0

Variable Pitch - Constant Speed Propellers

Configuration	N	D	πnD	M_t	B	Blade Width	η @102 Kt	η@58 Kt	Static Thrust	Weight
Modification 1	2250	6.5	765	.685	6	.58 basic	.82	.66	975	61.7
Modification 2	1500	7.5	588	.527	5	basic	.83	.70	1050	130.2
Modification 3	1125	7.5	441	.395	5	1.60 basic	.83	.78	975	239.0

SYMBOLS

D	Diameter, ft.
n	Propeller speed, revolutions per second
M_t	Propeller rotational tip Mach number
η	Propeller efficiency

Table A-II.- Summary of sound pressure levels for basic and modified propeller configurations

Propeller Configurations

Basic				Modification 1			Modification 2			Modification 3		
f, cps	mB	dB Calc	dB Meas	f, cps	mB	dB Calc	f, cps	mB	dB Calc	f, cps	mB	dB Calc
75	2	99	96.5	225	6	92	125	5	85	93.75	5	76
150	4	98	97.5	450	12	76	250	10	62.5	187.5	10	41.5
225	6	95.5	99.5	675	18	58.5	375	15	38.0			
300	8	92.5	91.5									
375	10	89.0	92									
450	12	85.5	90									

Symbols

m **Order of harmonic**

B **Number of blades**

db **Decibels**

APPENDIX B

ENGINE NOISE REDUCTION

By George M. Stokes

Previous work pertaining to aircraft engine quieting (refs. B-1 thru B-3) has demonstrated the technical capability in this field. The quieting of the aircraft using reciprocating engines requires the extensive muffling of the engine exhaust. When an extremely large level of noise reduction is desired, treatment of noise from other sources, such as engine intake, engine valves, blowers, and engine accessories, must be considered. Because of weight penalties and loss of performance, it is seldom practical to provide aircraft with the additives necessary for extreme noise reduction. In the quieting of the engine noise for the O-1 aircraft, only the exhaust noise is recommended for special treatment.

This appendix describes the procedure used to estimate the amount of noise reduction possible for different weight additions to the O-1 aircraft. Following is a step-by-step presentation of the procedure.

Method used to estimate engine-noise reduction.-

(1) Noise spectrum. The overall noise spectrum of the O-1 aircraft was measured at a distance of 50 feet from the engine exhaust. An engine noise spectrum was then derived, using the overall noise spectrum. Figure B-1 is a plot of this engine noise spectrum.

(2) The engine noise spectrum was studied in combination with the muffler theory of reference B-2. Single chamber resonators were selected for use in estimating the probable exhaust attenuation, although it is recognized that multiple chambered mufflers may be more optimum for high attenuation levels. Calculations were next made to determine the theoretical attenuation for a number of resonator mufflers. In order to achieve the largest exhaust noise reduction, the resonant frequencies used in the calculations were chosen with respect to null positions shown in the engine noise spectrum. Also, the tailpipe area was chosen with respect to the largest average exhaust velocity practical; this provided for the highest attenuation-to-weight ratio.

(3) The theoretical calculations were modified to more nearly conform to values expected under operating conditions. The modified attenuation spectrums were then compared with the engine exhaust noise spectrum, and the overall attenuation levels were determined for the muffler types selected.

(4) Muffler volumes were determined for each muffler computed.

(5) A noise reduction level of 3 dB is estimated to be achievable using the (original equipment) expansion chamber type muffler installed on the aircraft. It is assumed that this muffler will be replaced if the noise treatment indicated in this paper is followed.

(6) Exhausting all engine cylinders into a single muffler provides a much greater attenuation-to-weight ratio than a dual-exhaust system. Thus, the following steps are based on changing the dual-exhaust of the O-1 aircraft to provide a single-exhaust system.

(7) Muffler volumes were computed for attenuation conditions determined in step 3.

(8) Using the curves of volume versus weight (estimated by the method of Appendix C), the muffler weight additions were determined. For mufflers with less than 3 cubic feet of volume, an L/D of 0.25 was assumed with an under-cockpit installation. For mufflers larger than 3 cubic feet, an L/D of 0.5 was assumed with a fuselage installation.

(9) By making use of the information obtained in the foregoing steps, curves of overall engine noise versus weight addition were constructed. Figure B-2 shows the muffler types calculated and how the weight increased rapidly as noise reduction increases.

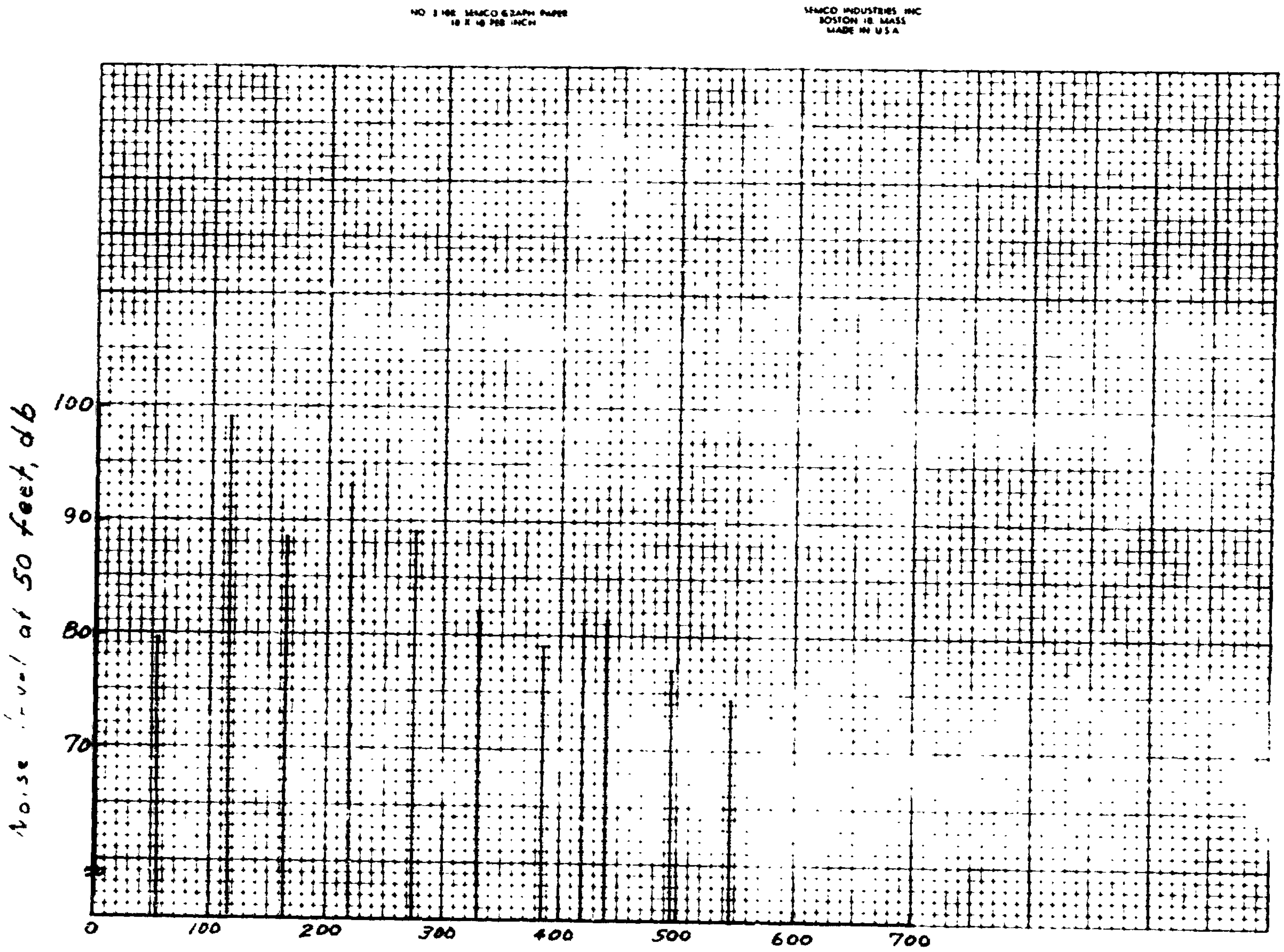
(10) The data of figure B-2 was used to select three special cases of noise reduction. Case 1 represents a noticeable noise reduction condition with a small weight addition to the aircraft. Case 2 represents a further increase in noise reduction with a noticeable increase in weight and volume. Case 3 represents the condition for the largest practical attenuation. This case is expected to require a fuselage installation for the muffler. Table B-I summarizes the pertinent muffler properties as they relate to the three cases selected. The estimated engine noise spectra for these three cases are illustrated schematically in figures B-3, B-4, and B-5.

REFERENCES

B-1. Vogeley, A. W.: Sound-Level Measurements of a Light Airplane Modified to Reduce Noise Reaching the Ground. NACA Rep. 926, 1949

B-2. Theoretical and Experimental Investigation of Mufflers with Comments on Engine Exhaust Muffler Design. NACA Rep. 1192, 1954

B-3. Johnston, G. W.: The Reduction of the External Noise Level of Otter UC-1 Aircraft. Rep. [illegible] H./24. The DeHavilland Aircraft of Canada, Ltd., July [illegible], 1[illegible]7



Exhaust noise frequency, cps

Figure B-1. Exhaust noise spectrum for untreated engine exhaust

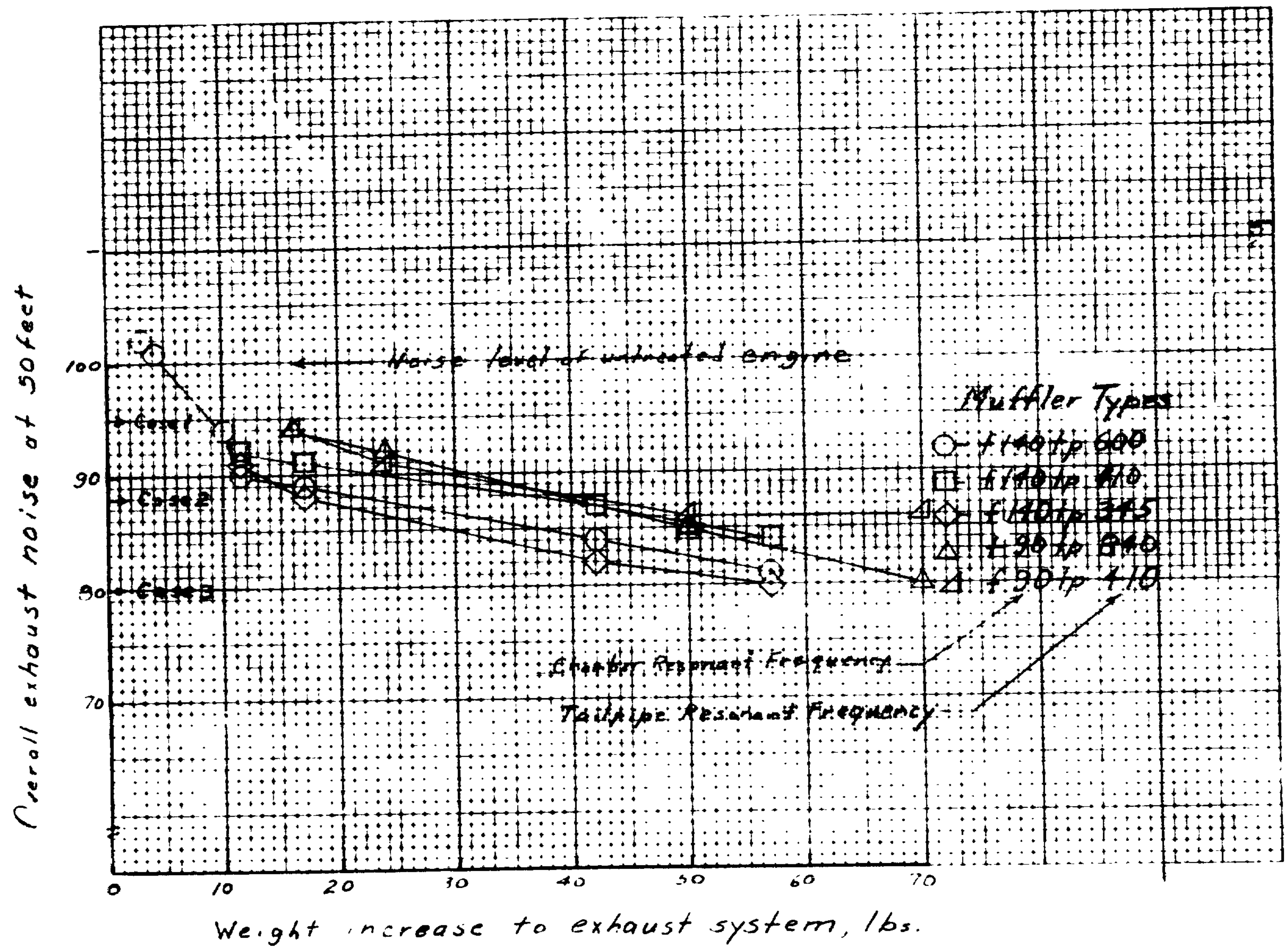


Figure B-2 Pr...ted overall noise ... for various

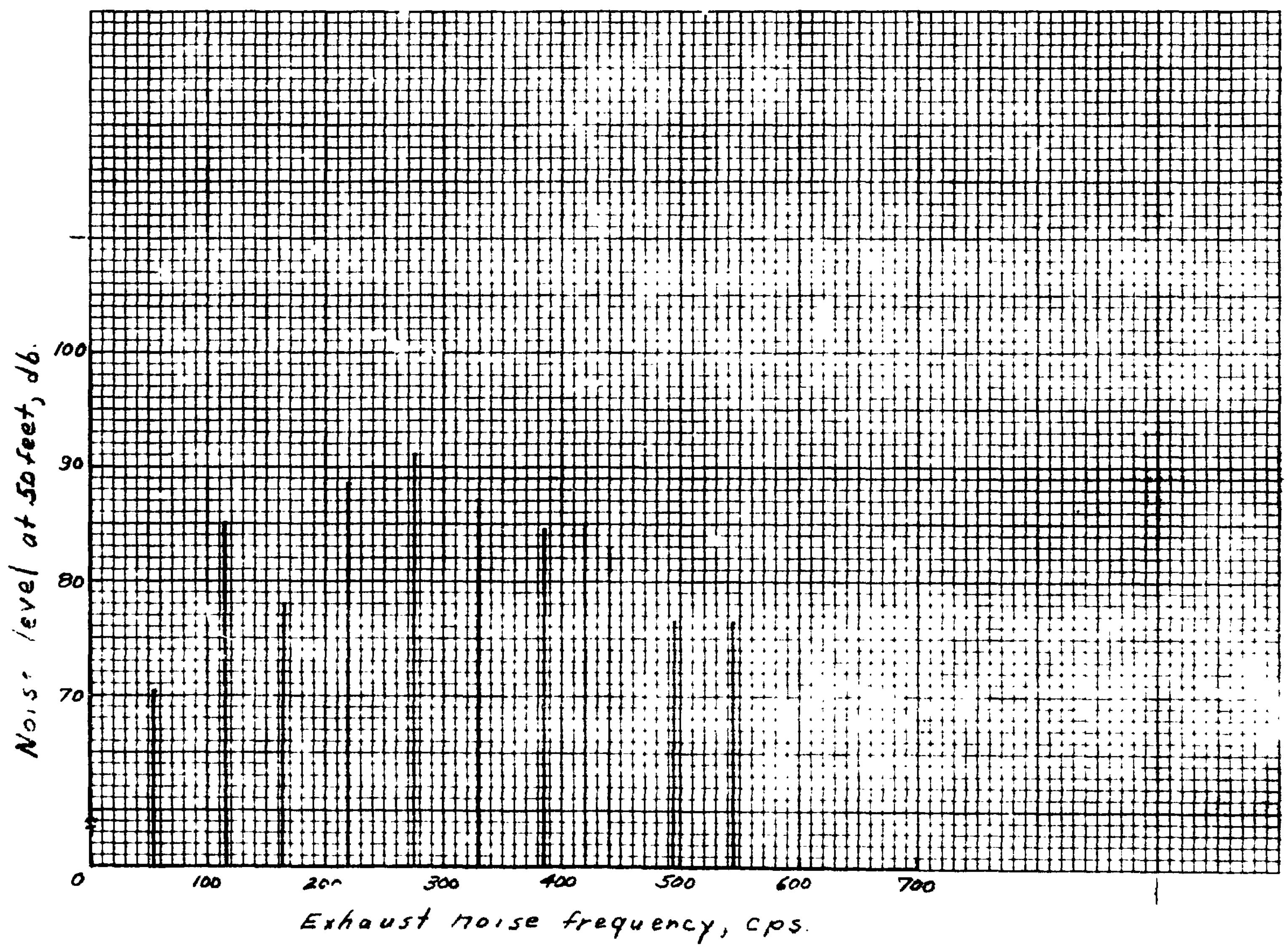


Figure B-3. Exhaust noise spectrum for Case 1.

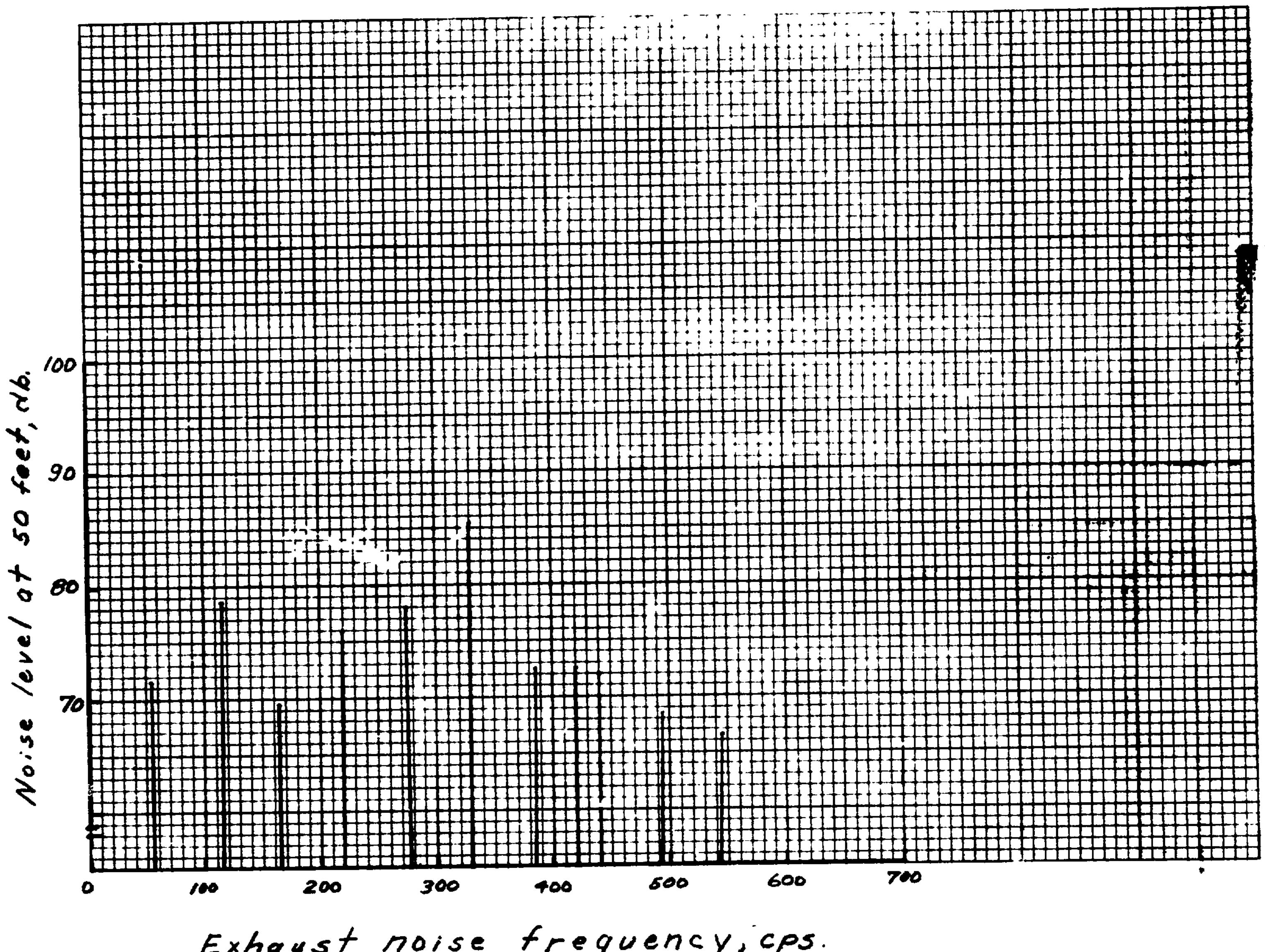


Figure B-4. Exhaust noise spectrum for Case 2.

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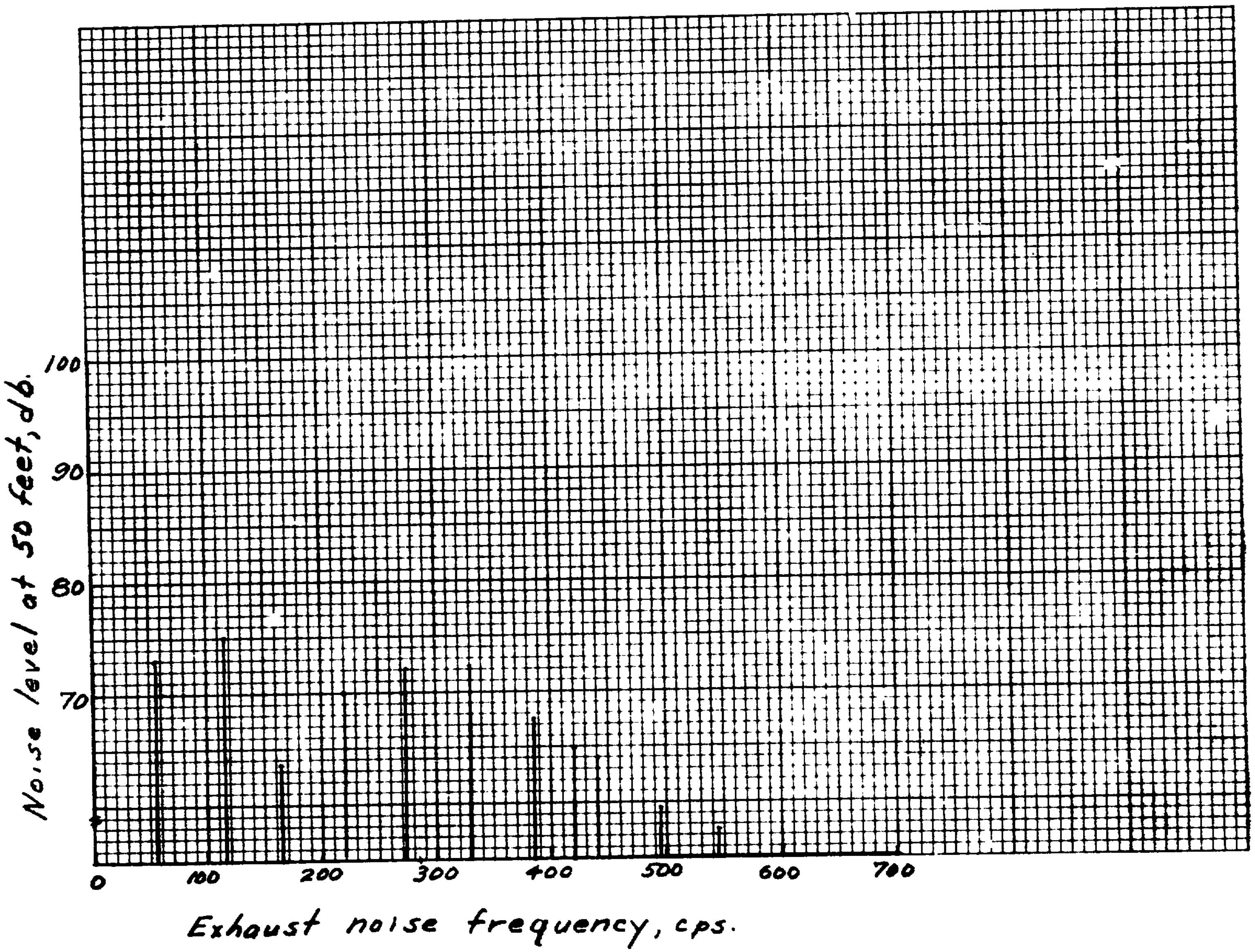

Figure B-5. Exhaust noise spectrum for Case 3.

APPENDIX C

WEIGHT ESTIMATES

M. L. Sisson

Weight Estimation of Exhaust System

The muffler configurations investigated were single resonator cavity type having a central tube approximately 2.5 inches inside diameter. This tube produces a gas velocity of about 500 feet per second under takeoff conditions. A series of effective volumes (total volume less central tube volume) ranging from .25 to 7 cubic feet and diameter to length ratios ($\frac{D}{L}$) of one, one-half, and one-fourth were selected. Weights were then computed on the basis of using stainless steel of 20 gage (.037 inch) for those less than one foot in diameter and 18 gage (.050 inch) for those over one foot in diameter.

The exhaust collector system was assumed to be modified by the removal of the two existing heater-mufflers which were estimated to weigh five pounds each. Two 2-1/8 inches outside-diameter .050-inch wall stainless tubes were angled downward aft to meet above the lower cowl surface. A wye about a foot long was formed which discharges directly into the muffler for the under fuselage muffler mounting. An additional length of ten feet of 2-7/8 inches outside-diameter .050-inch thick exhaust pipe was provided for muffler installation in the aft section of the fuselage. The use of this heavy wall for exhaust pipes provides allowance for mounting bracket weight. Weights were prepared for various lengths of tail pipe for tuning each muffler. All tail pipes were considered to be 2-5/8 inches outside diameter.

The increased weights of the systems were plotted versus muffler volume producing the curves of figure C-1.

Propeller Weight Estimation

Propeller blade weights, for the direct drive case, are based on scaling factors applied to the existing RAF-6 alum_ ·m alloy blade between R = 6 inches and R = 45 inches. This method considers that the thickness-to-chord ratio at each percentage of propeller tip radius station is maintained. The weight of each active aluminum alloy blade section becomes:

$$W_1 = \left(\frac{\text{chord}_1}{\text{chord}_0}\right)^2 \times \frac{\text{diameter}_1}{\text{diameter}_0} \times \text{weight}_0,$$

where subscript "0" refers to the original blade and subscript "1" refers to the new blade. A new thickness distribution curve (figure C-2) was applied to the 1.5 and 2.0 to one geared drive propeller blades. To this weight, a weight for an SAE or AND type shank and a transition section was added to produce the total blade weight. The shank sizes were selected to fair into the scaled propeller thickness distribution. For the direct drive, six-bladed propeller shank dimensions used were one-half of those for a size "0" shank. For the larger blades, a size "00" shank was used for the 1.5:1 gear ratio and a size "0" shank for the 2:1 gear ratio cases.

Steel hubs were sketched having sockets to fit the blades and a flange for mounting to the Continental engine crankshaft or reduction gear flange.

The additional weights required for controllable pitch propellers were calculated based on the weight of a two-bladed Hartzell controllable pitch propeller less the weight of a fixed pitch propeller. The scaling factor used was the total blade centrifugal force (centrifugal force per blade times the number of blades) raised to the eight-tenths power. As a check, this method was applied to the Hartzell 3-blade, 8-foot diameter, controllable pitch propeller used on the U-10 airplane giving weight agreement within one percent.

Weights for lightweight material (fiberglass or birch) blades including aluminum shanks and plates extending out into the blade section were computed. These weights are not included in **Table C-I** as these materials are considered to be unsatisfactory for military use due to their tendency to shatter on impact.

The engine gear weight for the 1.5:1 case was taken to be the same as Continental's standard gear (Gear Ratio = .688) which was obtained by subtracting the weight of the Continental IO-470 from the weight of the GIO-470. The weight of the 2:1 gear was assumed to be proportional to the output torque to the .84 power. Reference **C-1** is the source of the exponent used.

REFERENCE

C-1. PDB6101 Supplement A, Hamilton Standard Propeller Weight Generalization, January 2, 1963; Hamilton Standard Division United Aircraft Corporation.

Table C-I

Propeller Weight Estimate Summary

<u>Direct drive, 6 blade, 6.5 feet diameter</u>

Fixed, adjustable pitch	40.1 lbs.
Less weight of McCauley 1 $^{A}_{B}$ 200	46.1
Net weight increase	- 6.1 lbs.

Controllable pitch	61.7 lbs.
Less weight of McCauley 1 $^{A}_{B}$ 200	46.1
Net weight increase	15.6 lbs.

<u>Geared 1.5:1, 5 blade, 7.5 feet diameter</u>

Fixed, adjustable pitch, alum blade	74.2 lbs.
Engine weight increase	30.0
Total weight	104.2 lbs.
Less weight of McCauley 1 $^{A}_{B}$ 200	46.1
Net weight increase	58.1 lbs.

Controllable pitch, alum. blade	100.2 lbs.
Engine weight increase	30.0
Total weight	130.2 lbs.
Less weight of McCauley 1 $^{A}_{B}$ 200	46.1
Net weight increase	84.1 lbs.

<u>Geared 2:1, 5 blade, 7.5 feet diameter</u>

Fixed, adjustable pitch, alum. blade	165.8 lbs.
Engine weight increase	38.2
Total weight	204.9 lbs.
Less weight of McCauley 1 $^{A}_{B}$ 200	46.1
Net weight increase	157.9 lbs.

Controllable pitch, alum. blade	200.8 lbs.
Engine weight increase	38.2
Total weight	239.0 lbs.
Less weight of McCauley 1 $^{A}_{B}$ 200	46.1
Net weight increase	192.9 lbs.

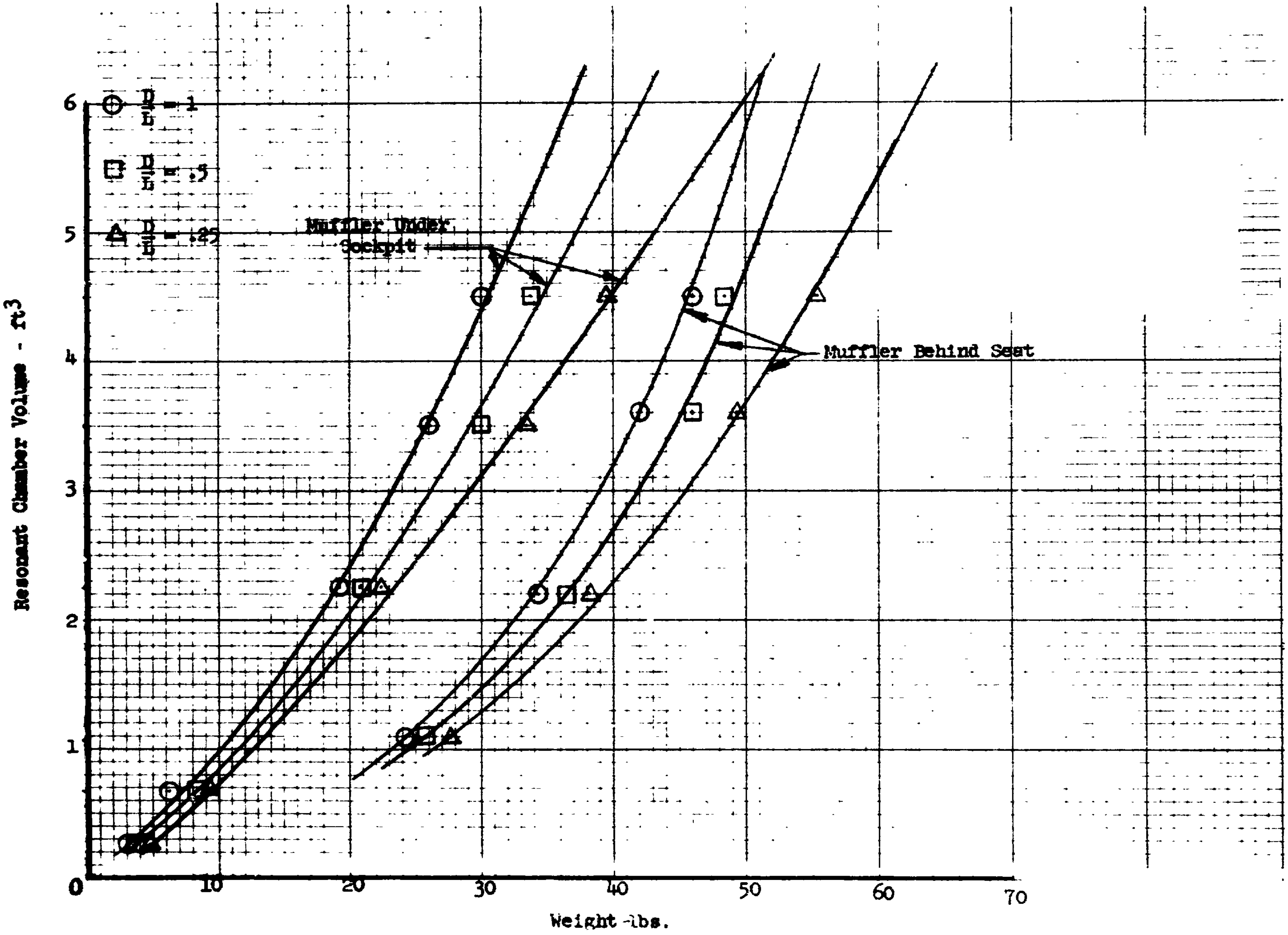

Figure C-1.- Estimated weights of O-1A airplane single resonator mufflers using various cavity volumes and diameter to length ratios

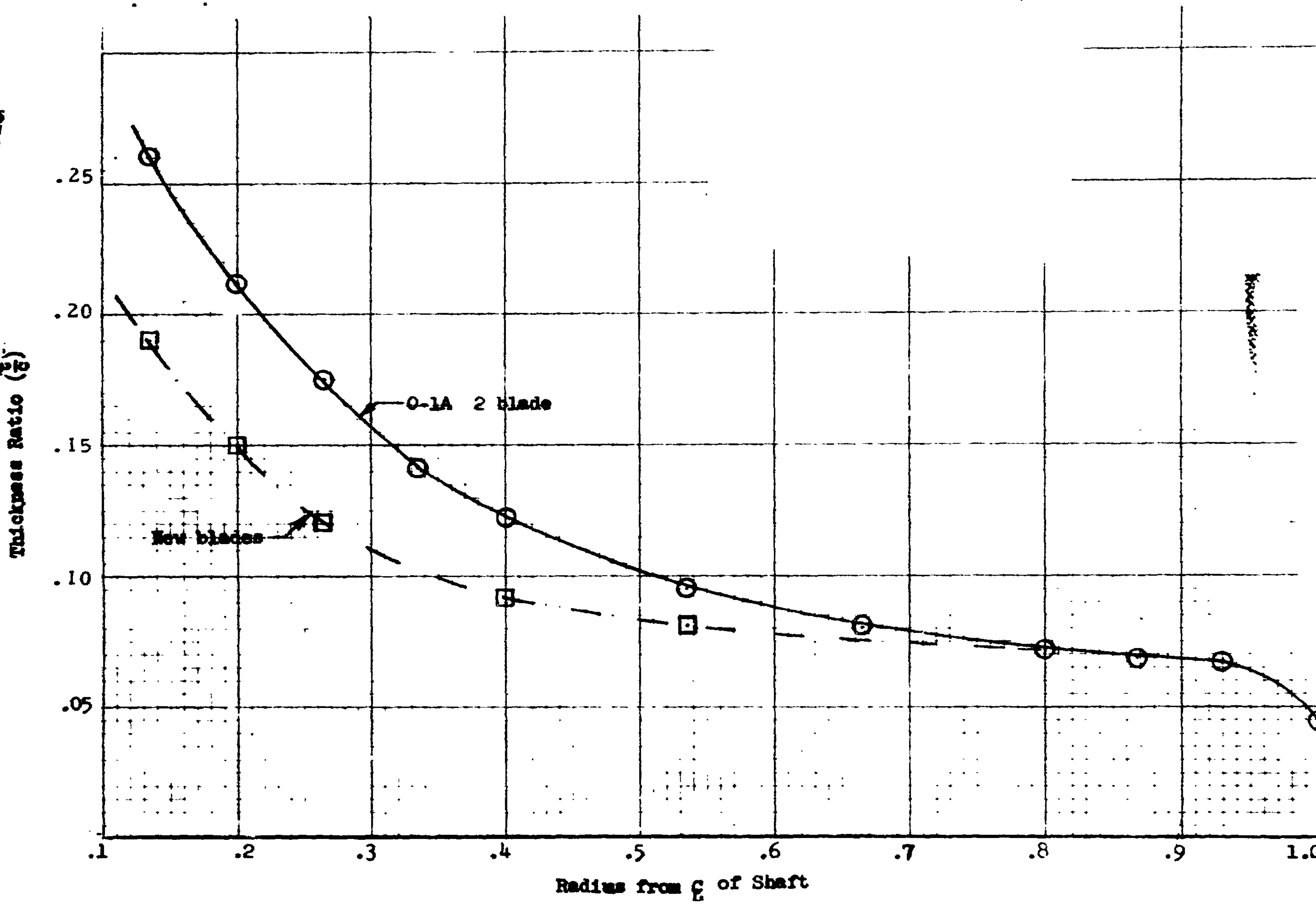

Figure C-2.- Thickness distributions of existing and proposed propellers for O-1A airplane.

APPENDIX D

Performance, Stability and Control

By James L. Hassell, Jr.

Method of estimating performance.- Flight test results reported in reference D-1 for the basic O-1A aircraft were used to obtain the brake horsepower required for level flight through the speed range. A propeller efficiency curve was established for the production propeller (McCauley 1A200 FM 9047) using information given in reference D-2 and the method of reference D-3, and the thrust horsepower required was thereby determined. The basic lift-drag polar was computed using the aircraft gross weight and the thrust horsepower required for level flight. Drag increments due to the external muffler modification were estimated and lift-drag polars were established for each modification. Thrust horsepower required was then calculated for each modification utilizing the applicable lift-drag polars and modified aircraft gross weights. The empty weights, useful load, and gross weights used in these calculations are given in Table D-I. Thrust horsepower available is a function of the engine brake horsepower, the power absorbing capability of the various modified propellers and the corresponding propeller efficiencies. The study was limited to sea level performance because of the intended application of the modified aircraft to low flight altitudes. Thrust horsepower available at sea level as a function of velocity was established for each modification. Flight performance was then calculated by the classical methods utilizing the established power required - power available data for each modification. The static thrust capability of each propeller was also established by the method of reference D- and the take-off performance was calculated using the static thrust values of each modification given in Table D-II and the variation of thrust with speed. Firm sod runway was assumed in these calculations.

Method of estimating stability and control.- The flight test results of reference D-4 were used for establishing the stick-fixed and stick-free neutral points for the basic O-1A aircraft from which the stability margins for the basic 2100-pound gross weight condition with center of gravity at 23.5 percent MAC were obtained. The results of the weight and balance summary given in Table D-I were then used to establish the stability margins for the various modifications. No modifications were considered of sufficient magnitude to affect the aerodynamic neutral points. Control effectiveness also was considered independent of modifications although control power would tend to decrease with the increased longitudinal stability associated with forward shift of the center of gravity.

Results of performance calculations.- Sea level performance calculations were made for the basic O-1A aircraft and for several modifications involving propellers, reduction gears and mufflers. The weight and balance summary given in Table D-I and figure D-1 indicated that all variations of modification 3 (heavy propeller and largest muffler) resulted in center-of-gravity locations so far forward that the structural design limit was exceeded by very large margins. Inasmuch as this modification is not deemed feasible without structural beef-up of unknown magnitude, detailed performance studies were therefore not made for modification 3.

The basis for the performance calculations are presented in terms of thrust horsepower required and thrust horsepower available and are given in figure D-2 for the basic O-1A airplane and in figures D-3 and D-4 for modifications 1 and 2 respectively. The power required curves shown in these figures are functions of the lift-drag polars presented in figure D-5 and the corresponding gross weights for the various modifications. It should be noted that the basic lift-drag polar was used for the modifications with internal mufflers. The power available curves were obtained by utilizing the propeller characteristics given in figures D-6 through D-10 which were derived from available data of references D-3, D-5 and D-6 and the utilization of propeller theory. The variation of thrust with velocity was also obtained utilizing the propeller characteristics of figures D-6 through D-10 and the results are presented in figure D-11.

A summary of the sea level performance values is presented in Table D-II. These results indicate that the modifications with fixed-pitch propellers require from 21 to 33.5 percent more take-off distance than the basic O-1A aircraft and also suffer 15 to 16 percent loss in rate of climb capability. Utilization of controllable pitch propellers (constant speed governing) results in modifications capable of equal or better performance than the basic O-1A aircraft. It should be noted that the O-1D and O-1F aircraft are presently equipped with constant speed propellers.

Results of stability and control study.- The stick-fixed and stick-free neutral points of the basic O-1A aircraft were unaffected by the various modifications. The resulting static margins (measure of longitudinal stability) are summarized in Table D-III. In all cases, increased longitudinal stability resulted from the more forward centers of gravity of each modification. Control effectiveness was not altered significantly by any of the selected modifications.

TABLE D-I

WEIGHT AND BALANCE SUMMARY

Case	Basic Weight Empty, lbs	Useful Load, lbs	Gross Weight, lbs	Gross Weight Center-of-Gravity, % $\bar{c}$
Basic	1607	493	2100	23.5
1-A	1610.5	493	2103.5	23.5
1-B	1632.1	493	2125.1	23.1
2-A	1682.1	493	2175.1	20.5
2-B	1696.1	493	2189.1	22.9
2-C	1722.1	493	2215.1	21.2
3-A	1816.9	493	2309.9	16.1
3-B	1826.9	493	2319.9	17.0
3-C	1861.9	493	2354.9	15.1

NOTE 1.- Useful load:

Pilot	200	lbs
Fuel	252	lbs
Oil	19	lbs
Cargo	22	lbs
Total	493	lbs

NOTE 2.- External mufflers located aft of engine cowl for cases 1-A, 1-B, 2-A and 3-A. All other cases have internal mufflers located within the aft fuselage section.

TABLE D-II

O-1A SEA LEVEL PERFORMANCE SUMMARY

ITEM	Basic -1A	1-A	1-B	2-A	2-B	2-C
Gross weight, lbs	2100	2103.5	2125.1	2175.1	2189.1	2215.1
Number propeller blades	2	6	6	5	5	5
Fixed or controllable pitch	Fixed	Fixed	Control	Fixed	Fixed	Control
Gear reduction	none	none	none	1.5:1	1.5:1	1.5:1
Muffler, cuft	Basic	.725 ext.	.725 ext.	1.54 ext.	1.54 int.	1.54 int.
SPL at 50 ft, dB	100	95	95	88	88	88
Ground run, ft	311	371	293	406	418	302
Air distance to clear 50 ft, ft	239	296	238	311	316	250
Total take off distance to clear 50 ft, ft	550	667	531	717	734	552
Percent difference from Basic	-	21% more	3.5% less	30% more	33.5% more	Same
Rate of climb, ft per minute	1290	1100	1300	1090	1105	1295
Percent difference from Basic	-	15% less	1% more	16% less	15% less	-
V_{max}, knots	115.9	115.6	115.5	115.0	115.8	115.8
V_{stall}, knots	36.5	36.5	36.7	37.1	37.2	37.7
V_{cruise}, knots	78.0	78.0	80	76	76	80.0
$V_{best\ rate\ of\ climb}$	58.0	63.0	58.0	59.0	64.0	59.0
Propeller efficiency, cruise	.83	.82	.82	.83	.83	.83
Propeller efficiency, climb	.65	.62	.66	.64	.64	.70
Static thrust, lbs	855	768	975	714	714	1050
Percent difference from Basic	-	10% less	14% more	16.5% less	16.5% less	23% more

TABLE D-III

SUMMARY OF LONGITUDINAL STABILITY MARGINS

Neutral Point	Configuration		
	Cruise	Power Approach	Landing
Stick Fixed	.55 MAC	.33 MAC	.50 MAC
Stick Free	.50 MAC	.41 MAC	-

STATIC MARGINS

CASE	Configuration		
	Cruise	Power Approach	Landing
Basic	.315	.095	.265
1-A	.315	.095	.265
1-B	.319	.099	.269
2-A	.245	.125	.295
2-B	.321	.101	.271
2-C	.338	.118	.288
3-A	.389	.169	.339
3-B	.330	.160	.330
3-C	.399	.179	.349

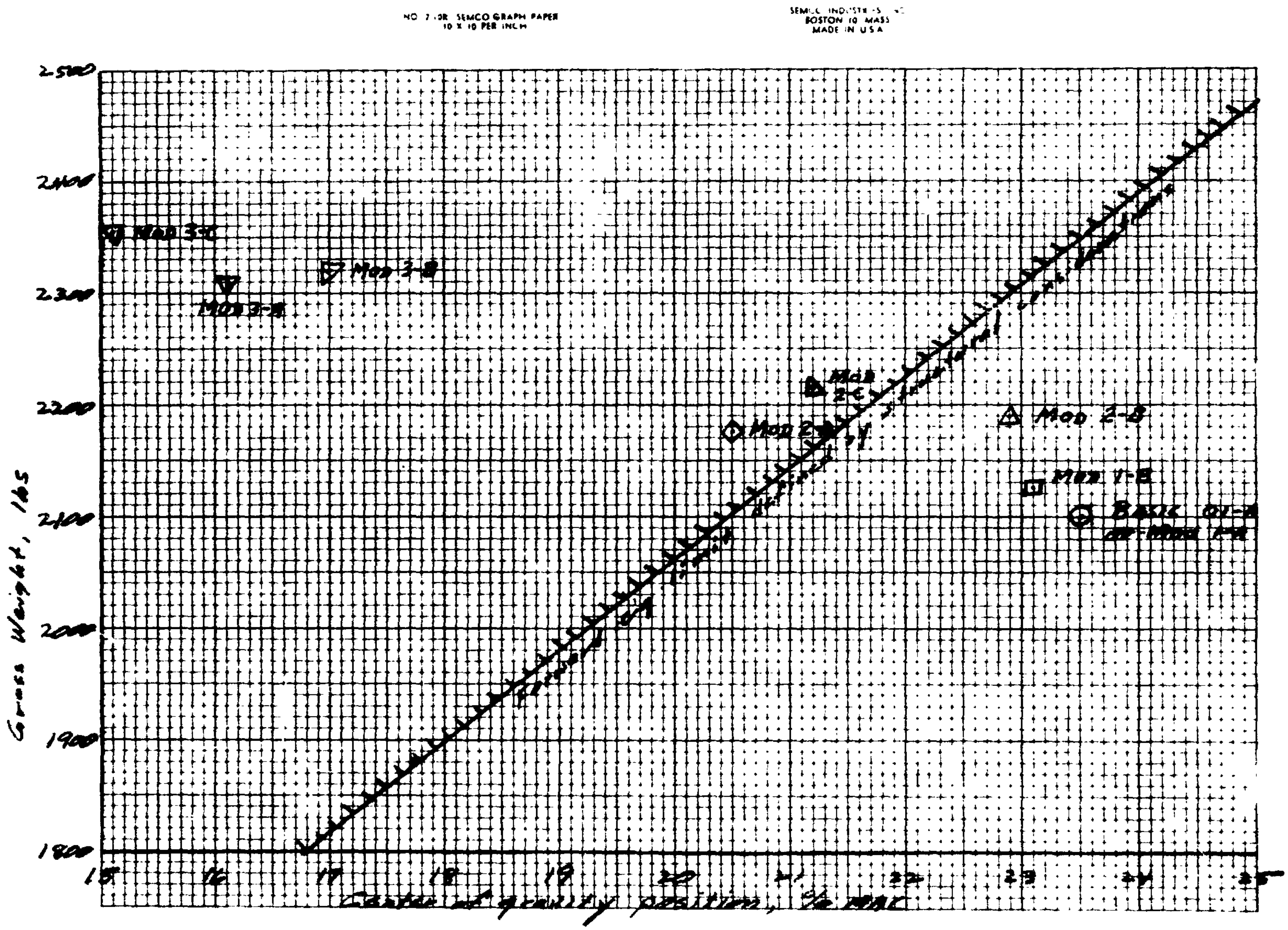

Figure D-1. - Effect of modifications on weight and balance as related to the forward center-of-gravity limit due to structural considerations.

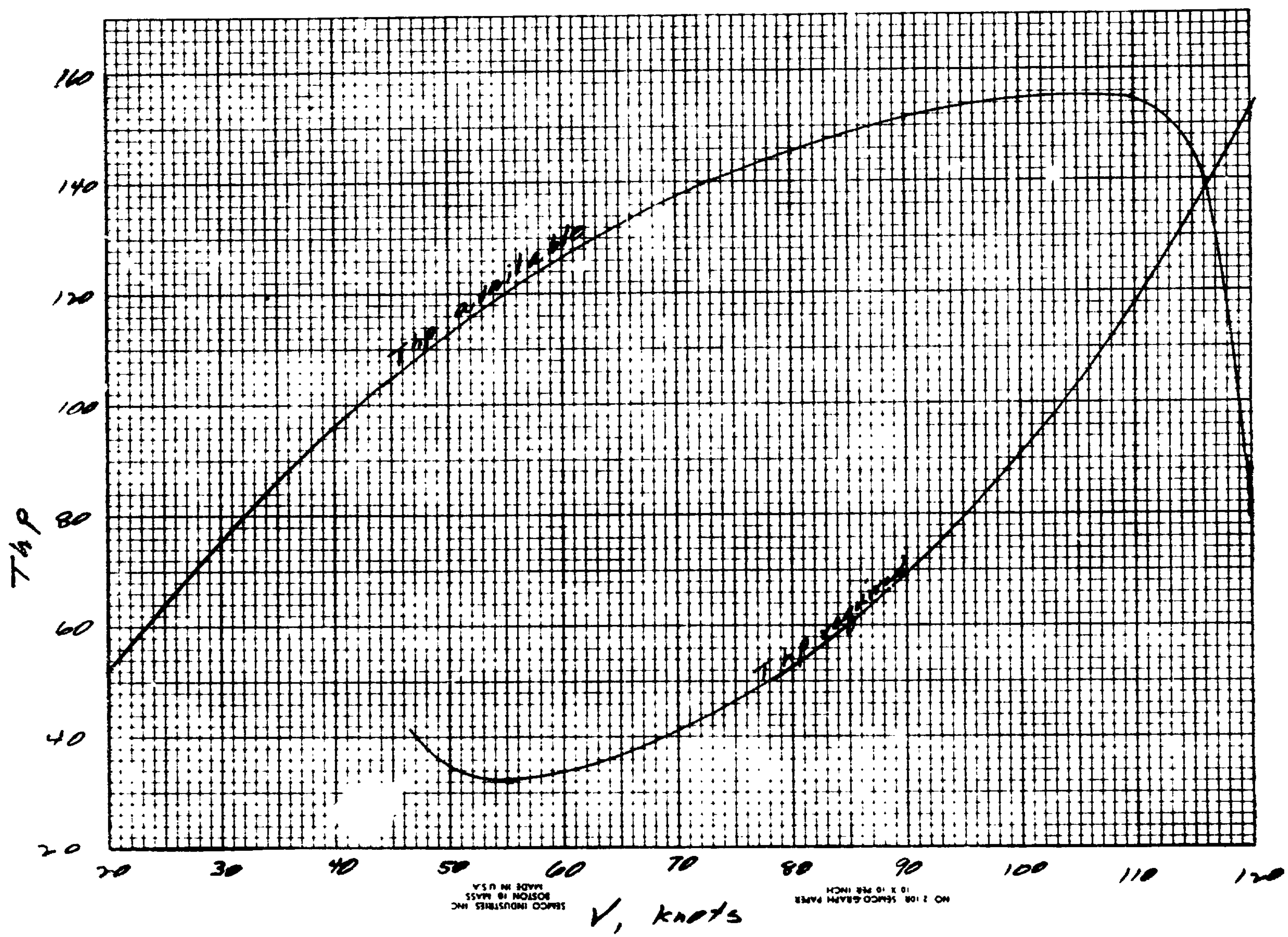

Figure D-2.- Power available and power required for basic O-1A airplane

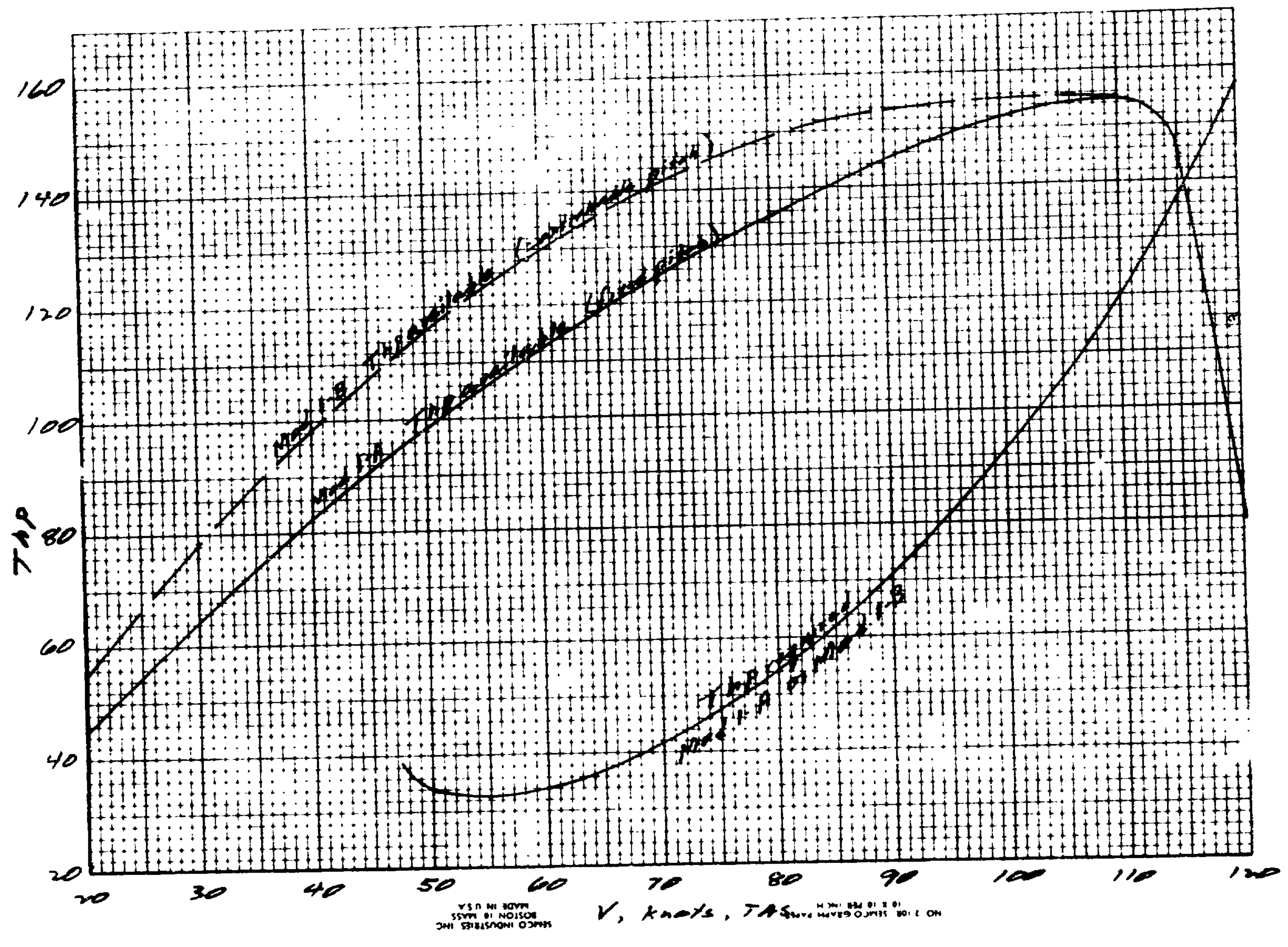

Figure D-3.- Power available and power required for modification 1.

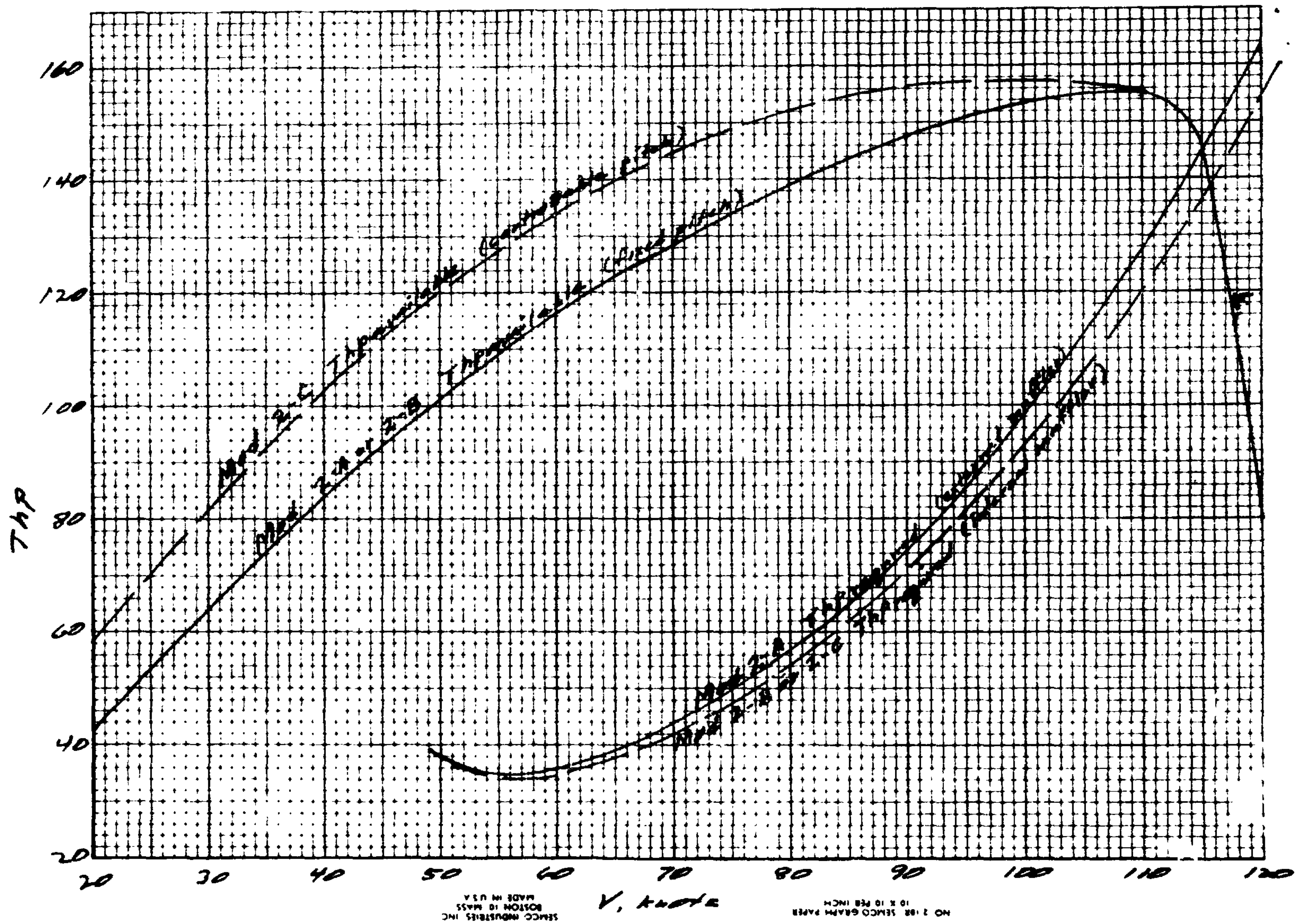

Figure D-4. - Power available and power required for modification 2.

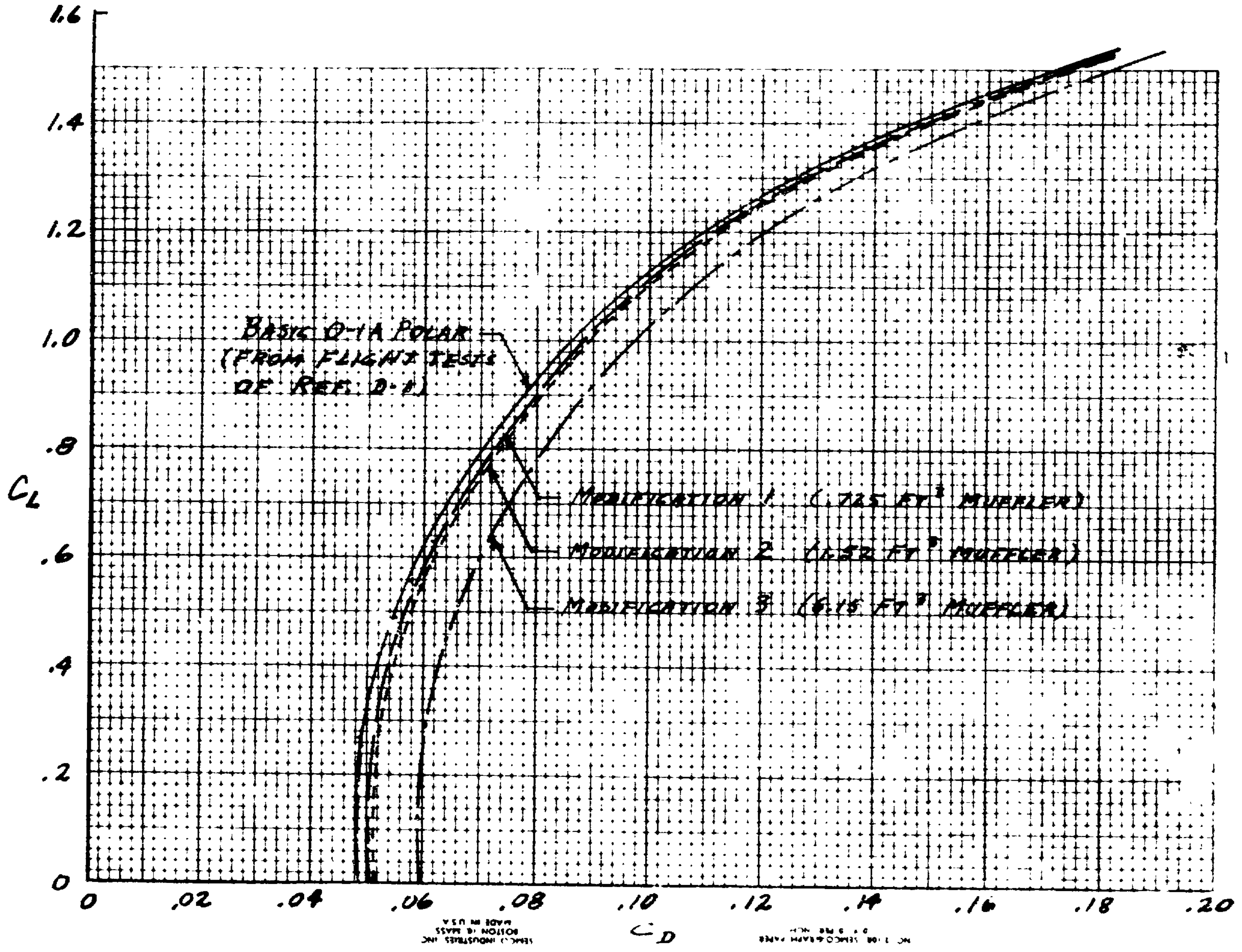

Figure D-5.- Lift-drag polars of basic and modified configurations

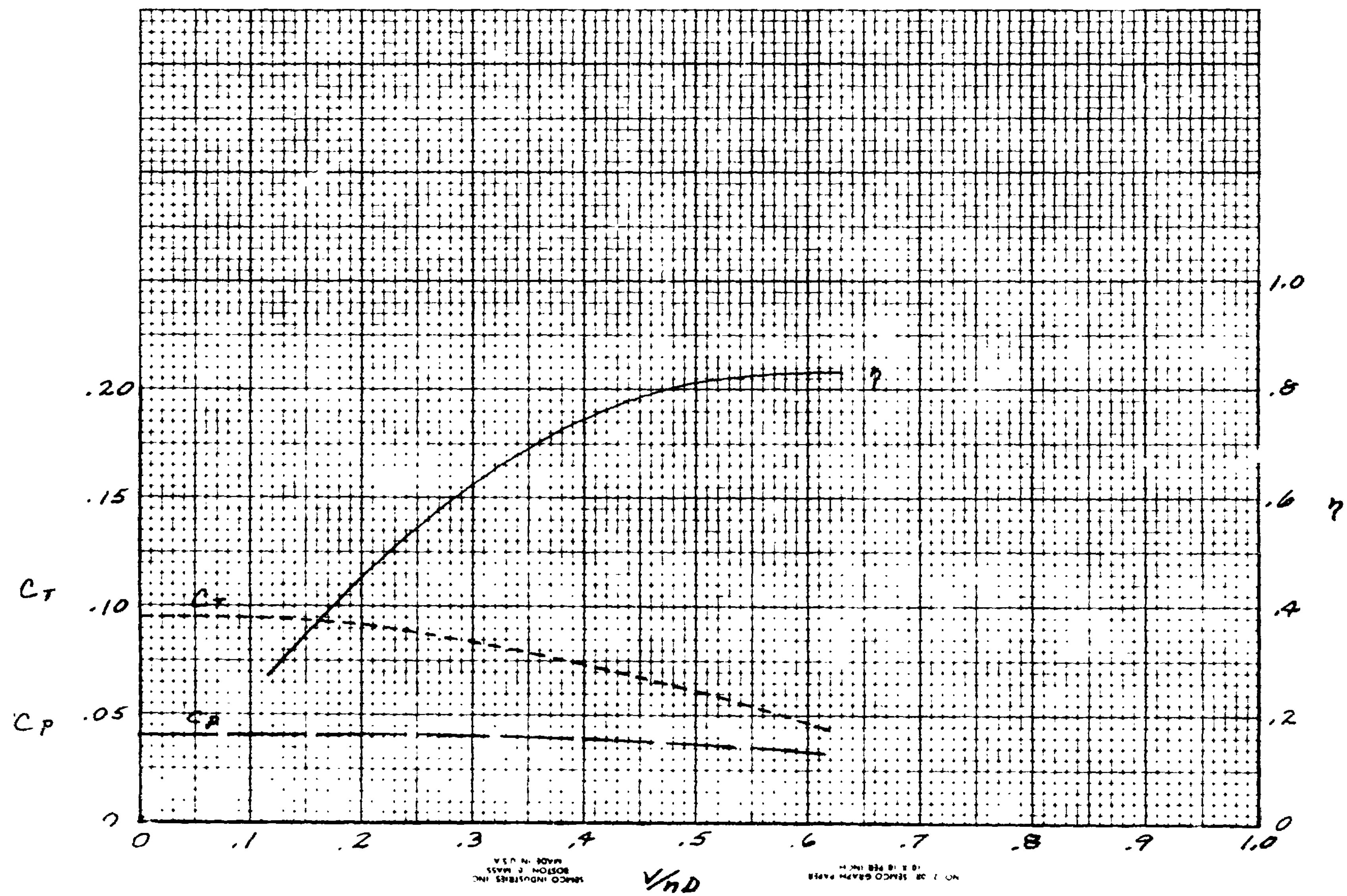

Figure D-6.- Propeller characteristics of basic O-1A airplane.
(2-blade, AF=90, McCauley 1A200 FM9047, 7.5 foot diam.)

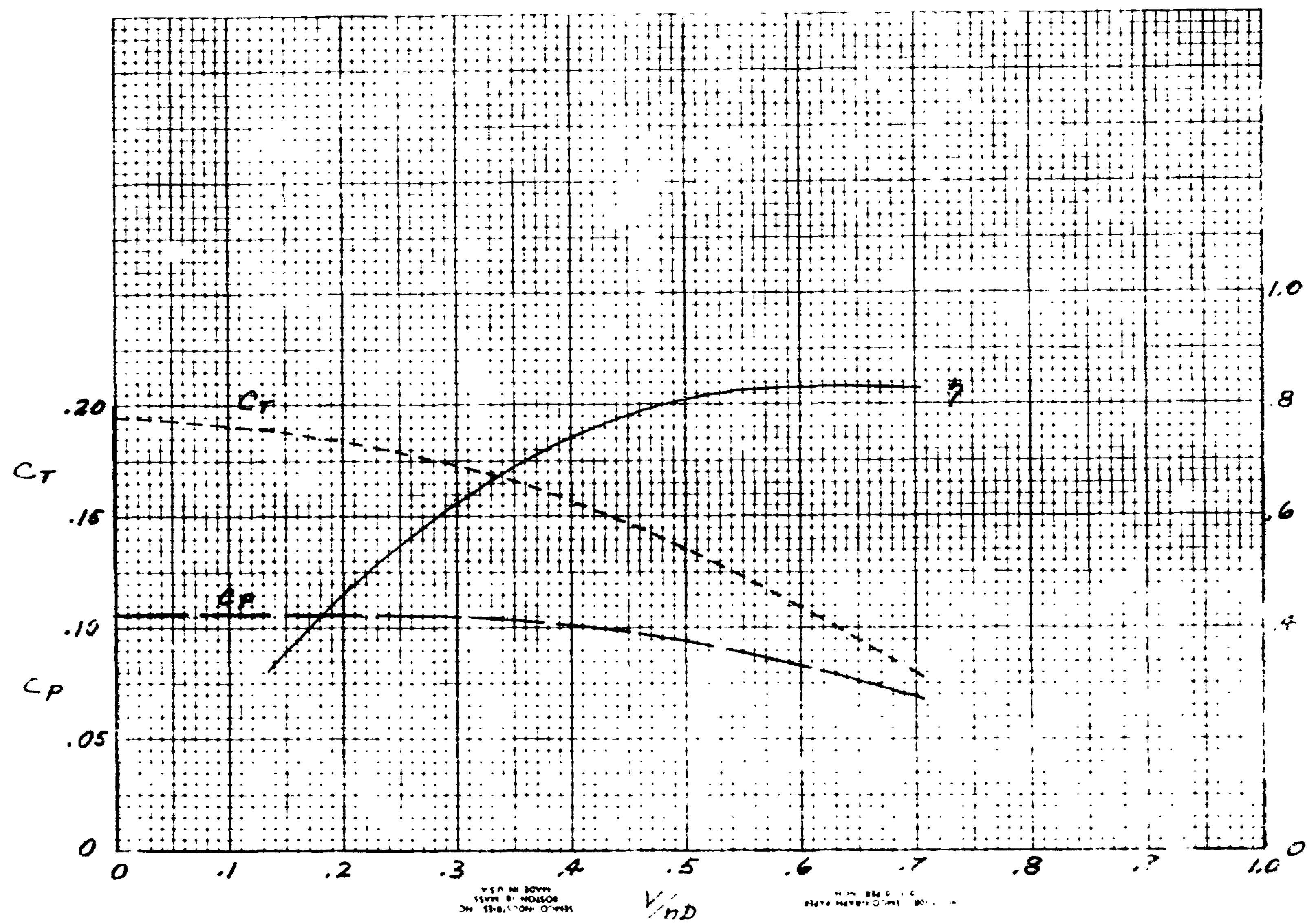

Figure D-7.- Propeller characteristics of fixed pitch, 6.5 foot diameter, 6-blade, AF = 52 propeller used for modification 1-A.

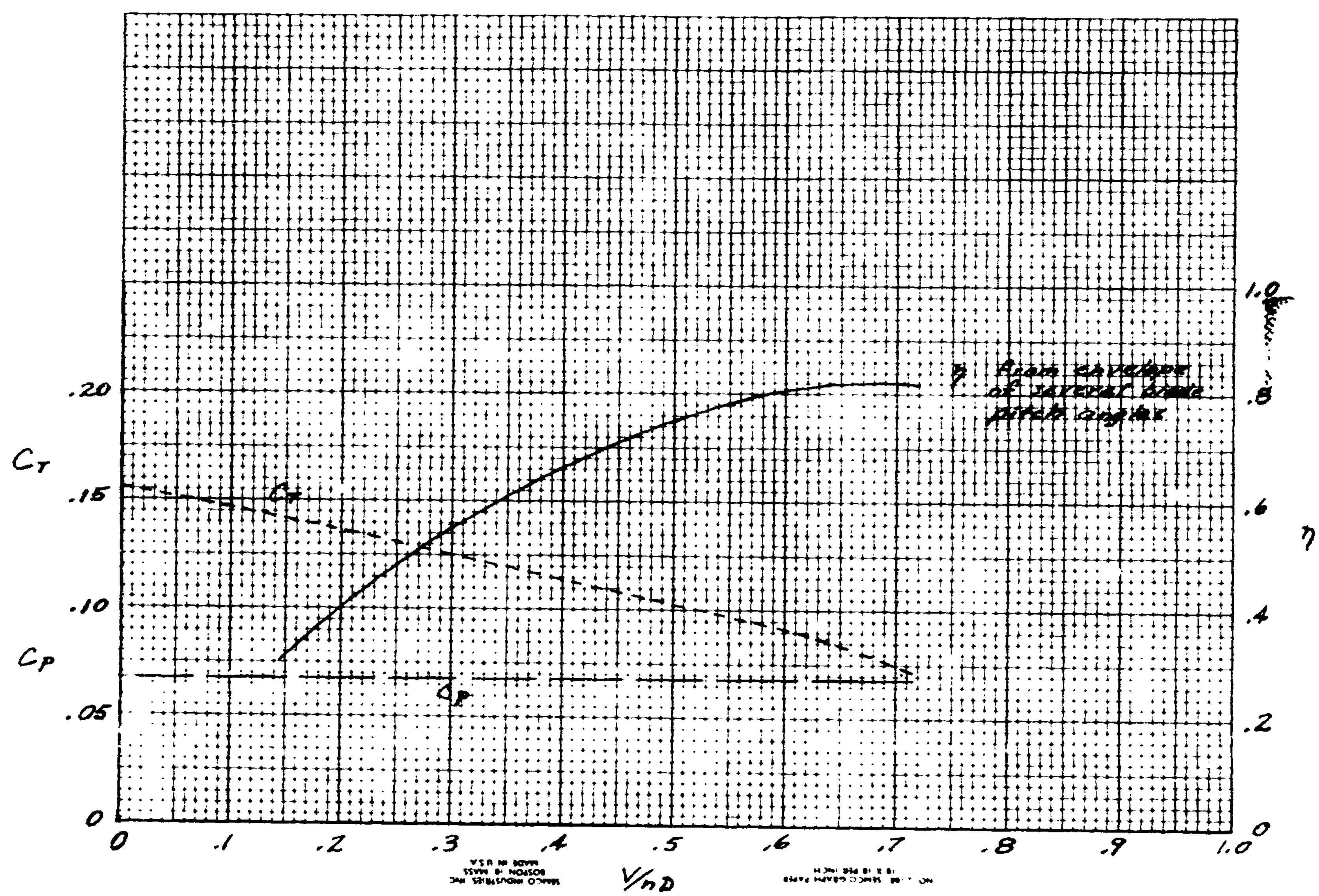

Figure D-8.– Propeller characteristics of constant speed, 6.5 foot diameter, 6-blade, AF=52 propeller used for modification 1-B.

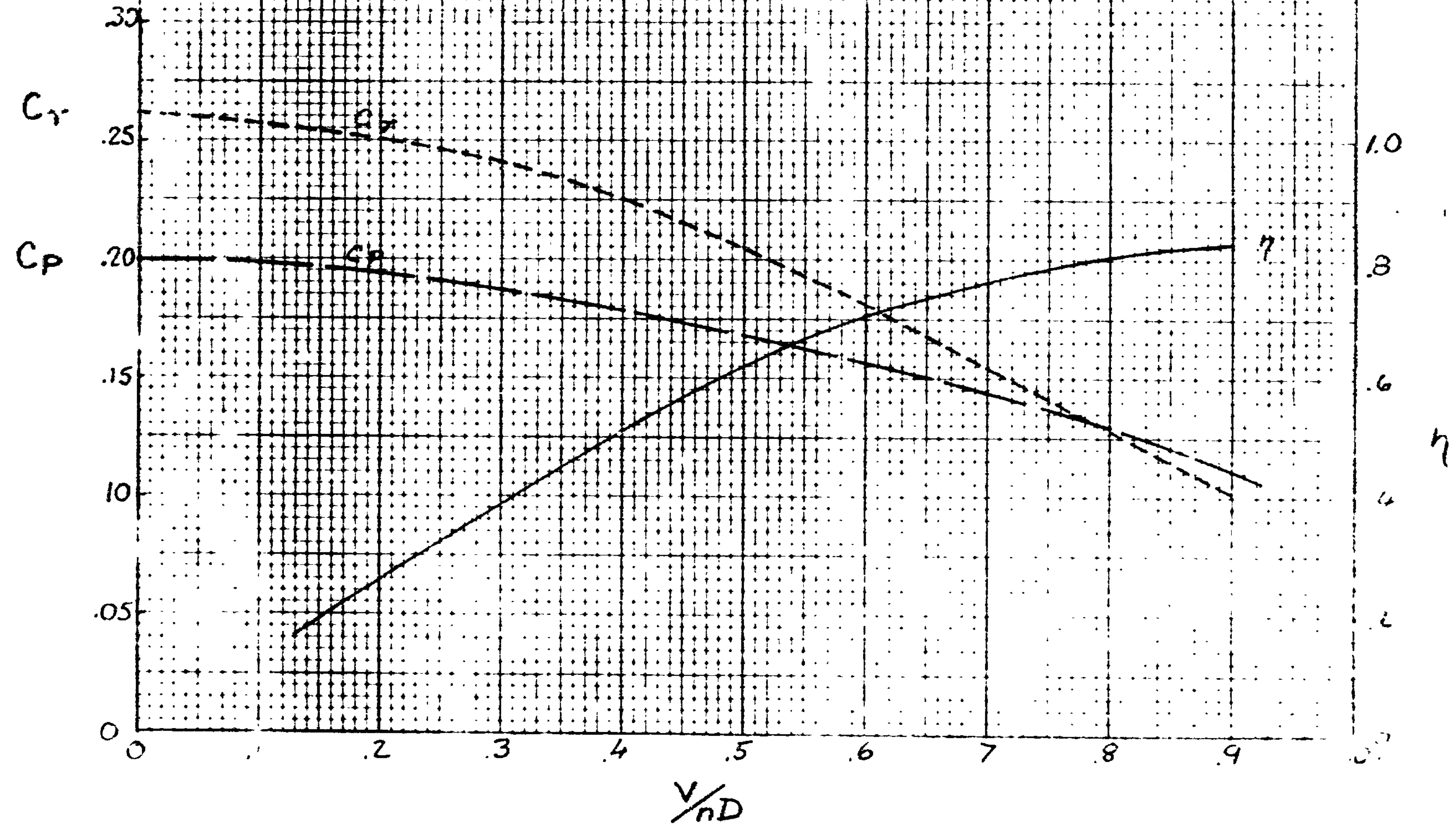

Figure D-9.- Propeller characteristics [illegible] fixed [illegible] diameter, [illegible]

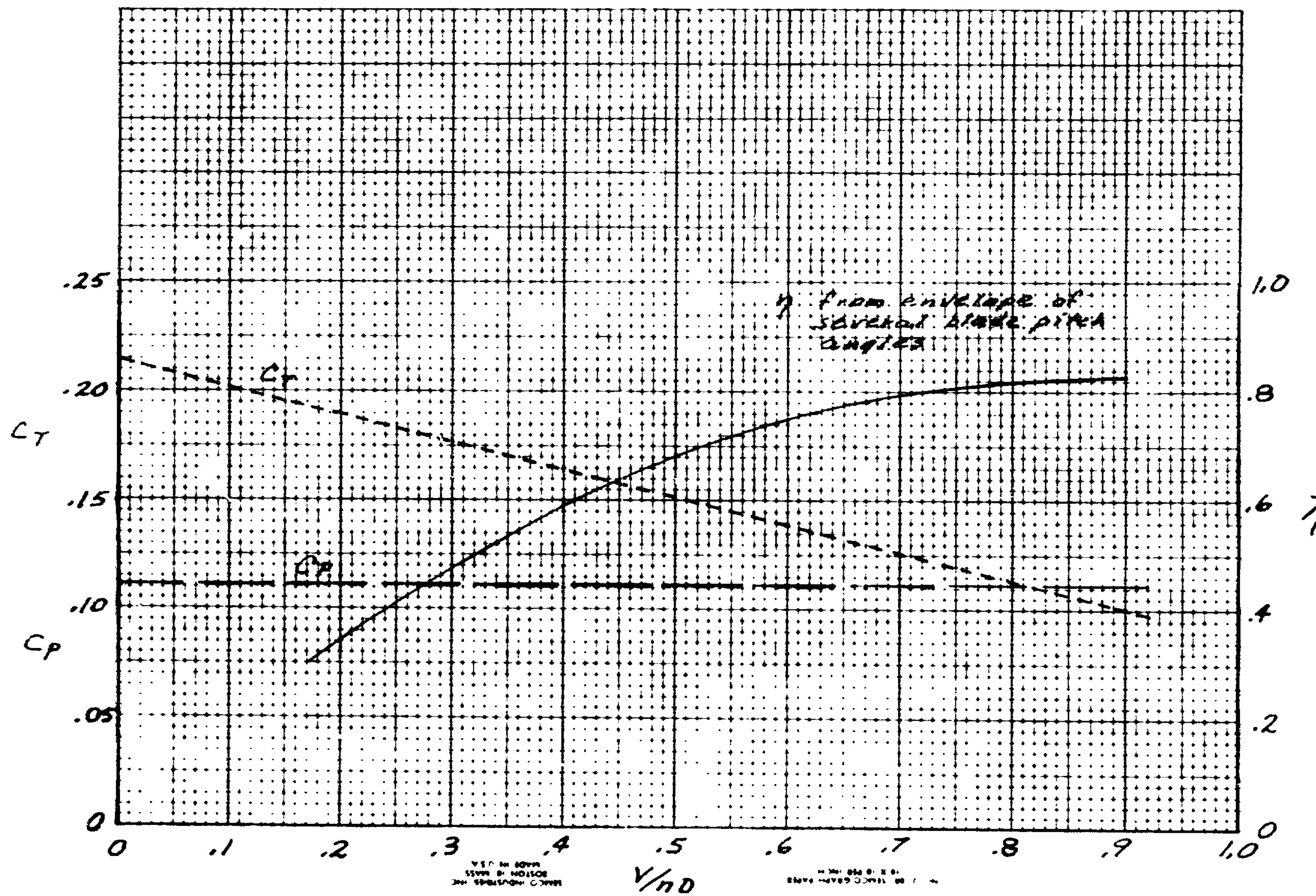

Figure D-10. - Propeller characteristics of constant speed, 7.5 foot diameter, 5-blade, AF=90 propeller used for modification 2-C.

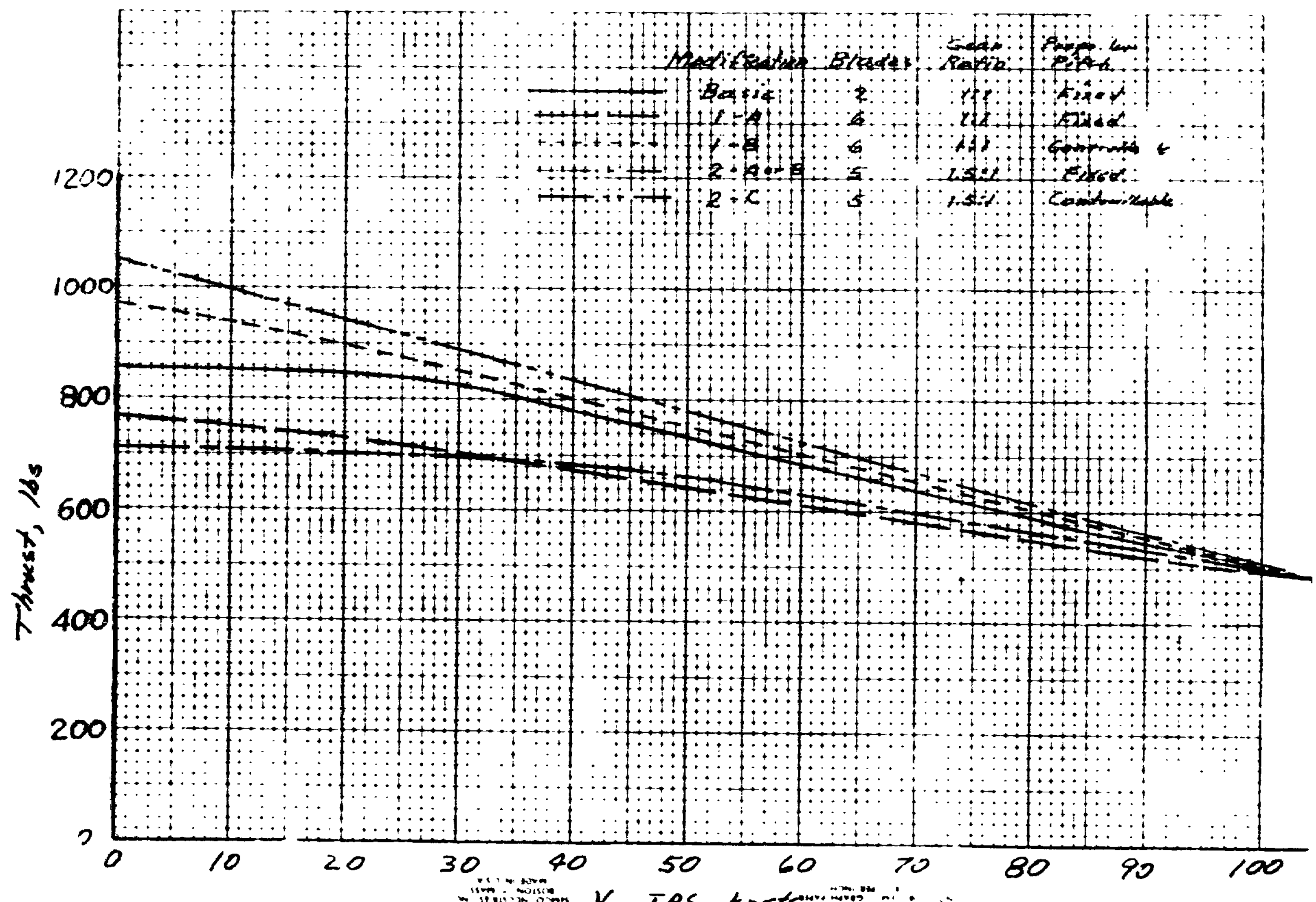

Figure D-11.- Variation of thrust with velocity for basic O-1A airplane and for several modifications.